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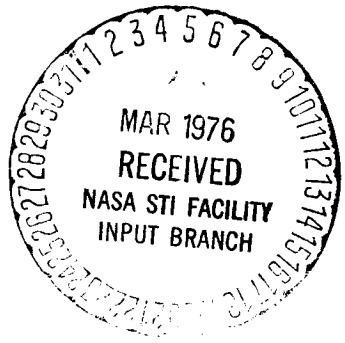

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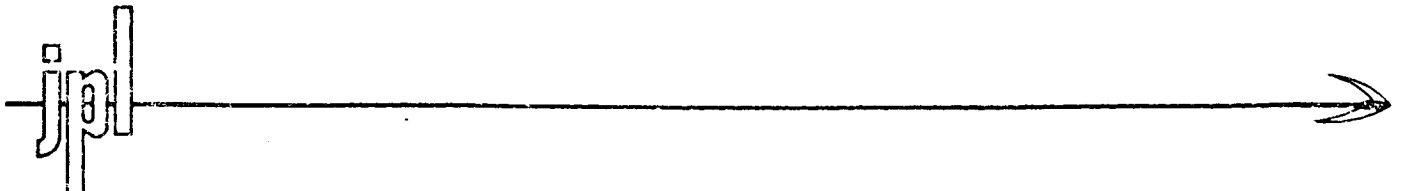

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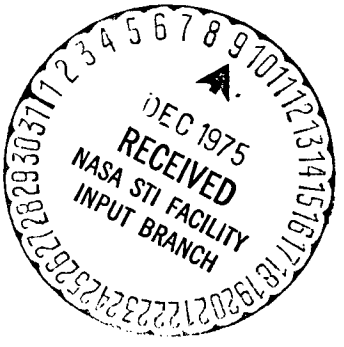

Atmospheric Pollution Sensing: Heterodyne Spectroscopy

NASA Work Unit 160-20-56-02-55

JPL 615-25620-0-3330

R. T. Menzies

Objective:

The general objective of this task is to develop sensing systems which utilize infrared laser technology for the remote monitoring of atmospheric pollutants from aircraft and spacecraft altitudes. The systems under investigation and development are of both passive and active types. The initial remote sensing instrument is an active laser absorption spectrometer, using a narrow bandwidth laser heterodyne radiometer as a receiver. A closely related passive heterodyne radiometer, using a wider IF bandwidth, is also being developed.

The objectives of FY'73 were to perform various laboratory and field measurements to demonstrate adequate sensitivity and selectivity. Construction and testing of a carbon monoxide laser local oscillator was to be completed; initial demonstrations to verify the sensitivity of an active system to selected pollutants were scheduled.

Progress:

Construction of a stable CO_2/CO laser system was completed during the first quarter. The laser structure was similar to a design by Charles Freed of Lincoln Labs, with modifications to simplify its construction and operation. It is equipped with a Littrow Grating-Mirror to permit selection of one lasing transition at a time. The unit can be operated as either a CO_2 laser or a CO laser by a relatively simple change. When operated as a CO_2 laser, the unit emitted several watts in a single line, single mode, and was passively stabilized to within $\pm$ 10 MHz of the line center. As a CO laser, the unit operates in the

5.1 - 5.6 μm portion of the spectrum, and emits 0.2 - 0.4 watts in a single line. The discharge tube is of a sealed type, and will operate 4-6 weeks on a single gas fill. (Utilizing our transportable laser filling station, the laser can be pumped out and refilled in a few hours time.) A second stable CO_2/CO laser was completed in June.

The ultrastable laser has been used to perform a number of significant experiments during the remainder of FY-73. Its main utilization has been as a source for a system to demonstrate the measurement of nitric oxide over an actual atmospheric path. It has been used in the laboratory as a local oscillator for a heterodyne radiometer to sense thermal emission from warm nitric oxide. When operated as a CO_2 laser, it was used to measure the beat frequencies of several pairs of lines of $C^{12}O_2^{16}$ and $C^{12}O_2^{18}$. These measurements provided better wavelength determinations of $C^{12}O_2^{18}$ laser lines, which were used to locate good spectral overlaps with SO_2 and O_3 in the 9.0 and 9.5-μm regions.

The carbon monoxide laser has been used in a system to monitor the amount of nitric oxide over actual atmospheric paths. The basic concept utilizes an overlap between an absorption line in NO and the 7-6, P(15) emission line of the CO laser at 5.187 μm. The nitric oxide monitoring system operates by a differential absorption technique. The CO laser is operated at a wavelength near 5.187 μm that does not overlap absorption lines of any atmospheric constituents, in order to obtain a "calibration" of the losses on the optical path being used. By measuring the relative transmission of the optical path at the two laser wavelengths, one overlapping the NO absorption line, and the other with no significant overlaps, the total amount of NO on the path can be determined.

We have demonstrated the operation of this system over a path between two buildings at JPL that are 400 meters apart. The experiment verified the operating concept, and measured NO levels that are consistent with those determined by the Los Angeles County Air Pollution Control District. The initial

measurements indicated that a minor overlap with water vapor exists. Measurements to check system accuracy are continuing, and an emphasis is being placed on precise measurements of water vapor transmission at various CO laser line wavelengths.

Plans:

Our immediate plans are passively to detect several room temperature pollutant gases (SO_2, O_3, C_2H_4, NH_3) with our wideband heterodyne radiometer in the laboratory, and to continue making atmospheric readings of pollutants with our active heterodyne instrument. With our active instrument we will focus on measuring NO and O_3. We plan to construct a new frequency shifter for this instrument which will allow for greater flexibility. Then we plan to transport the system to various locations and use several different background scattering surfaces to determine system sensitivities in practical flight conditions.

We also plan to construct several gas waveguide lasers in the laboratory. These lasers are more compact and simpler in design, and they look very promising as laser sources for our pollution monitoring instruments. These would be operated first as CO_2 lasers and then as CO lasers.

Publications:

R. T. Menzies, "Remote Detection of SO_2 and CO_2 with a Heterodyne Radiometer," Appl. Phys. Lett. 22, 592 (1973).

GEOLOGY/GEOMORPHOLOGY IMAGE PROCESSING

NASA: 160-75-10-01-55
JPL: 615-71001-0-8240

F. C. Billingsley

OBJECTIVE

To develop and demonstrate techniques of picture analysis which will be applicable to geologic problems. A tentative list of applicable processes includes linear feature enhancement by Fourier and spatial filtering, cluster methods using ratios, contrast enhancement, supervised and non-supervised classification using LARSYS and table look-up methods, photometric function effects and texture as signatures, thermal IR and multisensor correlations, and atmospheric correction.

The demonstration of the processing techniques will be accomplished by their use in solving geologic problems defined primarily by USGS personnel.

PROGRESS

1. Thermal-IR Rectification and Contouring (Rowan, USGS)

   We received a film print of a thermal infrared scan of an area near Lordsburg, New Mexico, a group of corresponding aerial photographs and a topog. map. The task was to digitize the infrared image, to geometrically stretch it to map the map, and to computer-contour the image. This was done, and a report sent to USGS.

2. Enhancement of Limonite Areas in an ERTS Picture (Rowan, USGS)

   An ERTS picture of Goldfield, Nevada (1072-18001, 3 Oct. 1972) has been extensively processed and color pictures produced. The primary processing has been computer contrast stretching to produce a high contrast pseudo-false-color-IR image, and ratioing of various spectral bands to produce a high contrast artificial-color image. The latter in particular shows mineralized areas in a quite different color than unmineralized, affording good visibility. During this effort we produced a large number of color images using various ratios and reproduced in various ways. These will allow future users to select optimum processing for his individual task. USGS personnel have used these image during aircraft overflights of the area to locate mineralized areas for further earth-based explorations. A publication is in preparation.

3. Enhancement of an ERTS Picture for Erosion Study (Morrison, USGS)

   Roger Morrison (USGS, Tucson) is studying erosion in Arizona, particularly the recent effects of grazing. He has supplied us with an ERTS picture (1102-17274, 2 Nov. 1972) for enhancement. We have contrast-stretched

individual spectral bands and made ratio pictures. These have been assembled into color pictures and sent to Morrison. We will continue to work with him to optimize the computer processing for his investigations.

4. Development Studies

In conjunction with RTOP 641-14-03-46 and an internal JPL-funded study, we have installed a version of the LARSYS multispectral analysis program, and have developed our own clustering and classification techniques. We have begun to use these, but further development is still necessary before meaningful comparisons can be made.

In conjunction with RTOP 641-14-03-46 we have developed several methods for treating the stripping of the ERTS pictures caused by the non-uniformity of the various sensors. This has been particularly necessary when computer processing the images, particularly where large contrast stretches are desired to bring out image detail. The results have been useful, but not yet adequate to eliminate all the stripping. Work is continuing.

We have begun a low-level effort toward mapping smog from ERTS pictures, based on the decreased local picture contrast seen in the presence of haze or smog. Our approach is to measure the local contrast at all points in a frame and to compare this point by point with a similar image made on a clear day. The comparison is to be done by ratioing one local contrast picture to the other point by point for each spectral band. Numerical analysis and/or color pictures made from the ratio images should show the degree of local contrast extinction, and perhaps allow estimation of the color of the haze. Preliminary pictures made this way look promising, but are very noisy. Much further work remains to be done; when the processing seems to be in hand, correlation with ground-based measurements will be necessary.

As a result of activities funded under this RTOP, the following ERTS-B proposals have been submitted:

Iowa Land Classification	J.V. Taranik Iowa Geologic Survey
Texture Analysis for Geology	H. Smedes USGS, Denver
Gulf Stream Dynamics	J. Apel NOAA, Miami
Ocean Studies	G. Maul NOAA, Miami

In addition, we are also working on two inter-agency tasks through contacts developed under this RTOP:

NOAA - Study of ocean dynamics by computer processing of ERTS pictures of New York, Cape Kennedy, and Miami.

USGS - Study of earthquake potentials by computer enhancement of ERTS pictures of Southern California.

FUTURE PLANS

In addition to continuation of tasks as outlined above, we plan activities in four areas:

1. New Geological Applications - Larry Rowan, our designated USGS prime contact, has proposed the following tasks:

Study Area	P. I.	Problem	Input Data
1) Iran	D. Kringsley	Study a desert playa	MSS CCT
2) Pakistan	R. Schmidt	Detection of mineralized zones (copper)	MSS CCT
3) Utah	E. Tooker	Detection of mineralization along the Uinta-Cortez belt	MSS CCT
4) a. Colorado	T. Offield	Discrimination of geologic materials	Multiband photo
b. Colorado	T. Offield	Detection of alteration zones in the Colorado mineral belt	MSS CCT and multiband photo
5) Malachite, Colorado	R. Watson	Discrimination of geochemical stressed trees.	Multiband photo

Appreciable further work is planned for the mineralized area enhancement, including other stretches, ratios and color combinations, a better calibration scheme, and a detailed analysis. It is felt that detailed processing on a certain area will yield results not possible by a shotgun approach.

2. Completion of the backpack field spectrometer and its utilization to gather ground-based spectra.

3. Study of lineament structures at varying sun angles via the use of topographic relief maps, in conjunction with Don Wise of the University of Massachusetts.

4. Work with the state of Arizona in locating water sources for Flagstaff using data from our ERTS pictures.

In addition to all the above, we are broadening our base by applying these and related computer techniques to other earth resources problems (e.g., fresh and salt water and land use studies) from other funding sources.

RADAR OCEANOGRAPHY

NASA Work Unit 160-75-17-01-55

JPL 615-71701-0-8230

W. E. Brown, Jr.

OBJECTIVE

The objective of this task is to apply linear coherent radar techniques to the measurement of various ocean phenomena in support of Earth and Ocean physics programs. Specifically, the task was directed toward airborne observation and measurement of sea-state, ocean wave spectra and surface patterns.

PROGRESS

The JPL 25 cm imaging radar was flown on the NOAA C-130 over the coast of Florida, Gulf of Mexico, and the Pacific Ocean south of Acapulco. Very clear imagery of ocean waves and surface patterns was obtained and the data are presently under study. On some of the imagery, a number of interesting patterns were visible which seem to be internal waves. This mission has definitely established the capability of coherent imaging radar to image the ocean surface and it confirmed our previous imagery over the southern coast of Alaska. The preliminary results of this mission will be presented during the 1973 URSI meeting in Boulder, Colorado.

During the same mission, we developed and we tested for the first time a real-time altimeter and a "phase jitter" instrument which measures the jitter in the phase of the leading edge of the echo. We are presently processing the measurements and will relate them to the surface roughness and sea state.

PUBLICATIONS

W. E. Brown, C. Elachi, and T. W. Thompson, "Oceanographic Observations with Imaging Radar," URSI Meeting, Boulder, Colorado (1973).

VLBI Earth Physics
NASA RTOP 161-79-64
JPL 690-96401/402/404

P. F. MacDoran

OBJECTIVE

To conduct Very Long Baseline Interferometry (VLBI) studies, research and experiments to demonstrate the feasibility of

a) the ARIES (Astronomical Radio Interferometric Earth Surveying) concept for accurate three dimensional earth crustal measurements

b) simultaneous two-frequency VLBI for calibration of charged particle effects.

ACCOMPLISHMENTS

Data Analysis/Technique Development

In order to achieve a full three dimensional baseline vector measurement, it is necessary to obtain the interferometer time delay function. Using a variation of a technique suggested by A. E. E. Rogers of MIT Lincoln Laboratories, a two channel bandwidth synthesis technique was developed which was compatible with DSN equipment configurations. By recording with a 24 kHz instantaneous bandwidth at 2270 and 2310 MHz on alternate seconds, it was possible to synthesize the interferometer delay function with sub-nanosecond precision.

In August and twice in October 1972 experiments were conducted using this 40 MHz synthesis technique with JPL Hydrogen Maser frequency systems at DSS12 (Echo) and DSS14 (Mars) stations on the Goldstone Complex. The results of those three experiments were that a 4 cm precision was obtained for all three baseline components.

The comparison of the 4cm radio interferometric result with the geodetic survey values between DSS12/14 showed agreement in the baseline cord length (within the 20 cm first-order accuracy of the geodetic survey) but an apparent rotation of coordinates frames which amounted to 60cm pointing vertically relative to the Goldstone horizontal. To date the most likely explanation of the 60 cm difference lies in the method of vertical geodetic control. The radio interferometer is inherently a geometric measuring method while the method of differential leveling used in the survey to determine the difference in vertical height of two locations is explicitly dependent on a knowledge of the local gravity. The Goldstone area and indeed the entire Mojave desert has a complex structure in its deflection of the vertical owing to inhomogeneous subsurface mass distributions and its associated gravitational effects.

The possibility that the 60cm difference could be coming from a systematic radio instrumentation effect was investigated. Phase variations at the 2270 and 2310 MHz channels of the S-band traveling wave maser are present but their systematic effect on the baseline solution is less than 10cm if uncalibrated. With explicit calibration these phase variations will contribute only about a 1cm error.

It is intended to use the portable station to aid in the evaluation of how accurate a radio interferometric measurement can be. The first portable station experiments (September 1973) will be with the portable station 300m east of the Mars station. Over this 300m line-of-sight separation, the baseline vector can be determined without local gravitational effects complicating the determination of the vector separation. This

300m will be independently determined with 1cm accuracy. It will be the goal of this first experiment to obtain the correct result to within the 9m/64m interferometer inherent noise limit, approximately 4cm. The 300m baseline experiment will allow the evaluation of the portable station's performance without concern for the effects of Universal Time, Polar motion, radio source position uncertainties and transmission media effects.

The ability to calibrate UT and polar motion effects and to develop a radio source catalog of sufficient accuracy to support ARIES baselines of 300km lengths has been investigated. Using S-band data acquired in the summer of 1971 between Goldstone (DSS14) and Madrid, Spain (DSS62), it has been possible to establish a preliminary catalog of approximately ten extragalactic radio sources whose relative positions are known with accuracies between 0.1 and 0.01 arc sec.

The software systems developed on the basis of the Goldstone/Madrid experience will be of significant value in designing and executing a similar set of Goldstone/Madrid observations at S and X-band simultaneously in order to remove the effects of charged particles. These charged particle effects limit S-band data accuracy at about 1.5m baseline equivalent level. Using the S/X feed and electronics of the portable station on the DSS61 Spain antenna, a simultaneous S/X band VLBI experiment will be conducted with the Goldstone/Mars station in order to derive a radio source catalog of 20 or more sources, accurate to 0.01 arc sec. With 0.01 arc sec positional accuracy, a 300 km ARIES baseline can be measured with only 1.5cm contributed by the radio source error. Such an S/X band experiment was planned for FY'73, in conjunction with the MIT Haystack Observatory. However, the

experiment was not possible because necessary S-band modifications to the MIT antenna which could not be performed due to budgetary restrictions.

The effect of tropospheric water vapor was studied. Using published historical precipitable water vapor data for the period 1946-1956, it was possible to estimate, within 3cm, the zenith radio path delay effect in the Goldstone area for the year 1967. Furthermore, the historical precipitable water data indicates that between Goldstone and San Diego, California not more than a 5cm difference is to be expected throughout the year. Thus, the water vapor error source appears to be correctable at the 5cm error level by means of historical data. By flying radiosonde weather balloons and taking surface weather data at ARIES sites and the Goldstone area, the water vapor effects will be calibrated to better than 2cm.

Because of the high baseline measurement accuracy required for geophysical applications it was previously estimated that only a hydrogen maser frequency system would be adequate to the VLBI Earth Physics task. However, the expense and lack of field ruggedness of the hydrogen masers made them unattractive for portable VLBI station use. Therefore, a study of the explicit effect of the frequency/time subsystem and a search for an alternative to the H-maser was undertaken.

In October and November 1972, experiments were conducted on the DSS12/14 baseline using a newer design Rubidium Vapor frequency system (HP 5065) at DSS12 with a JPL H-maser at DSS14. The results were that the baseline was measurable with an 8 cm three dimensional precision with baseline component values in agreement with those derived by the H-masers.

Furthermore, the 4cm results obtained previously by the JPL H-masers were limited by signal to noise parameters and not the H-masers. It was then possible to estimate that the H-maser noise of 1 part in 10^{14} was contributing only a few millimeters of baseline noise.

Based on the experience with the H-maser and Rubidium frequency systems it was possible to estimate the performance required to meet an ARIES baseline accuracy goal of 1 to 3cm and it is equivalent to $\frac{\Delta f}{f} = 8 \times 10^{-14}$ or better over a 3 hour period. A new high performance cesium beam resonator is now commercially available (Hewlett Packard model 5061 option 004) which meets such a specification. This is a development of significant importance because it will allow an ARIES transportable station to utilize a $20K cesium - beam reference instead of a $200k or more hydrogen maser reference. This $180k or greater difference contributes directly toward a less expensive ARIES station initially but perhaps more importantly, the cesium-beam system is considerably more portable and ruggedized translating into a more efficient field operational configuration for ARIES stations.

The data recording system intended for ARIES station use is of the NRAO (National Radio Astronomy Observatory) Mark II design. Mark II data was recorded on a DSS12/14 baseline experiment along with the 24 kHz used in all previous VLBI Earth Physics experiments. Progress is being made in understanding the many subtleties involved in using the Mark II hardware/ software systems that already exist but were never intended to do the type of phase measurements that VLBI Earth Physics requires. The Mark II data has been interfaced to the first stages of the bandwidth synthesis software. It is anticipated that a Mark II baseline solution will be completed within the first quarter of FY'74. This solution will of course be compared with the 4cm precision solution obtained with the 24 kHz mode. The Mark II

solution should have a precision of 1cm or better.

A SIRD (Support Instrumentation Requirements Document) has been prepared which covers the demonstration of the ARIES feasibility station. The SIRD requests support for experiments through December 1974 at which time the ARIES station will have measured a grid of four points within the Los Angeles basin. The four points will be selected on the basis of having independent geodetic measurement already available or which can be made. ARIES accuracy can then be assessed by the ARIES station ability to reproduce existing geodetic control by differencing baseline vectors relative to Goldstone. The search for Los Angeles basin sites with existing high accuracy geodetic control has been started with the assistance of J. C. Savage, USGS, National Center for Earthquake Research and the cooperation of the Los Angeles County Surveyor's Office. Several sites appear favorable particularly from the viewpoint of minimal site preparation costs.

Instrumentation/ARIES Station

Office of Applications, EOPAP, funding of the VLBI Earth Physics Instrumentation Work Unit was not made available until half way through the fiscal year. The work unit was divided into two principal tasks in support of bringing an ARIES feasibility station into existence. The tasks were in the areas of radio frequency and mechanical subsystems.

The ARIES station is being designed for reception at S-band initially because FY'73 dollar resources were not sufficient for an X-band RF and mechanical implementation. In FY'74, X-band will be added to the initial S-band subsystem. An RF feed of the Mariner Venus/Mercury spacecraft antenna design type will allow simultaneous S/X band reception on the ARIES station. The IF output of the S-band and later X-band receivers

will be input into the existing NRAO Mark II high rate digital recording terminals.

The antenna electromechanical systems were in rather poor condition as received from the U.S. Army as surplus. Some mechanical upgrading (new drive motors and amplifiers) which were originally planned for FY'74 had to be undertaken with FY'73 funding.

For the initial S-band experiments, the ARIES antenna will be pointed by means of manually entered precision rate commands to the antenna's azimuth and elevation axes. The antenna angles as a function of time and for a given radio source will be precomputed and made available to the antenna operator. Such an antenna pointing method will be satisfactory for S-band reception where the beamwidth is one degree. However, with an X-band beamwidth of ¼ degree a computerized pointing system is a virtual necessity and will be implemented in FY'74. An ADP (Automatic Data Processing) plan was prepared in July 1972 and forwarded to NASA Headquarters; no approval has been received to date. Since computer pointing could not be implemented because of a lack of FY'73 funding and no approved ADP plan, manual ARIES antenna pointing is the only remaining option. As a point of information, the radio flux from an extragalactic radio source used for VLBI Earth Physics is too small to change the 9m antenna temperature sufficiently to "peak-up" on the source. Pointing of the 9m antenna will therefore of necessity be done "in the blind."

Meetings and Symposia Papers

"VLBI Earth Dynamics" by P. F. MacDoran, Fourth Annual Precise Time and Time Interval Conference, Goddard Space Flight Center, November 16, 17, 1972.

"ARIES (Astronomical Radio Interferometric Earth Surveying): Research Into the Earthquake Mechanism" by P. F. MacDoran, 42nd Annual Meeting of the Society of Exploration Geophysicists, Anaheim, California, November 27-30, 1972

"Radio Interferometry: Feasibility Demonstration for Monitoring Tectonic Motion" by J. B. Thomas, J. L. Fanselow, P. F. MacDoran, D. J. Spitzmesser and L. Skjerve, American Geophysical Union Meeting, San Francisco, Calif. 5 December 1972.

"The Equatorial Projection of a California/Spain Baseline and Irregularities in the Earth's Rotation Rate as Obtained by a Radio Interferometer" by J. L. Fanselow, P. F. MacDoran, J. B. Thomas, J. G. Williams, D. J. Spitzmesser, L. Skjerve, J. Urech, American Geophysical Union Meeting, San Francisco, California, 5 December 1972.

"Radio Interferometry for Study of the Earthquake Mechanism" by P. F. MacDoran, Conference on Tectonic Problems of the San Andreas Fault System, Stanford University, 20-23 June 1973.

External Publications

"Very Long Baseline Interferometry (VLBI) Earth Physics", by P. F. MacDoran, Proceedings of the Fourth Annual NASA and Department of Defense Precise Time and Time Interval (PTTI) Planning Meeting, 14-16 November 1972, Goddard Space Flight Center, X-814-73-72.

ATMOSPHERIC EXPERIMENT DEVELOPMENT

Nasa Work Unit 185-47-71-01-55
JPL 601-47110-0-8250
C. B. Farmer

OBJECTIVE

The purpose of this work is to define in detail the key measurements to be made by instruments on planetary mission spacecraft in order to satisfy the basic scientific objectives in the most complete and efficient manner allowed by the mission design constraints. The immediate results are experiment concepts defined in terms of spectral coverage, spatial and spectral resolution, sensitivity, etc. These are tailored to individual planetary projects proposed by NASA and formed within a continually updated framework of: (a) present knowledge of the atmospheric system in question, (b) the outstanding goals of NASA and the scientific community in general, and (c) the state of the art in the relevant technology. Novel and improved methods for the interpretation of the measurements, and supporting Earth-based and laboratory experiments where necessary, are also defined and implemented.

PROGRESS

During the past year, the objectives related to the initial exploration of Jupiter and Saturn by remote sensing have been completed. A comprehensive study of radiative transfer processes in hydrogen-helium-methane-ammonia atmospheres was concluded, and the results applied to detailed analyses of available ground-based data (Publications 3-5, 10, 11, and others in preparation). The techniques involved will have direct relevance to the interpretation of MJS and C-141 data when these become available. Their high accuracy depends on the use of data on the spectroscopic properties of the relevant molecules obtained under this task, existing data being largely inadequate or non-existent. Ammonia, methane and deuterated methane were studied under hydrogen-broadening conditions in the JPL spectroscopy

Laboratory. As a result, new compilations of spectral line data for NH_3 and CH_3D have been published; and existing data on line strengths for CH_4 have been revised (publications 4, 7, and in preparation). The measurements of hydrogen-helium mixtures under Jovian conditions requires very special apparatus and was performed under contract by G. Birnbaum of Rockwell International. These results permitted a revision of the theory of pressure-induced absorption in hydrogen. The part of this work which relates to the helium enhancement of the hydrogen spectrum was abandoned due to funding cuts in January 1973.

Radiative transfer in the Jovian clouds was also studied. The optical constants and scattering parameters of solid ammonia particles were determined from a dispersion analysis of published spectra (publication 6). A highly efficient and very accurate algorithm for radiative transfer calculations in inhomogeneous multiple scattering atmospheres was developed from the earlier work of Redheffer and Grant and Hunt and adapted to make possible the calculation of simulated spacecraft measurements from realistic atmospheric models.

The theoretical techniques and spectroscopic data described above were incorporated into theoretical studies and error analyses of methods for the study of atmospheric composition and cloud structure on Jupiter and Saturn from spacecraft measurements. The results of these, together with the techniques developed earlier for temperature profile and H_2/He ratio determination, formed the basis of a proposal for the MJS mission.

Preliminary studies of the feasibility of determining the hydrogen to helium ratio in Uranus by measurements from the projected Mariner Jupiter-Uranus and Pioneer Saturn-Uranus spacecraft were performed. The optimum wavelength coverage and spectral resolution requirements were defined to be 200-400 cm^{-1} and $\sim$30 cm^{-1}, respectively. The performance levels of tentative instrument concepts for each mission were analyzed and found to be satisfactory for MJU, but marginal for PSU. Further study of this topic is planned.

Most of the second half of the past year was devoted to the study of the problem of remote sensing of the temperature structure of the upper

atmosphere of Venus from the 1978 Pioneer orbiter. Conventional temperature sounding instruments were found to be capable of making measurements only in the region close to the cloud tops. An experiment concept and preliminary instrument design has been generated which makes use of the pressure chopping technique (Taylor et. al., Applied Optics, 11, 1, 135, 1972) originally developed for remote sounding of the Earth's mesosphere from Nimbus F. When optimized for the Venus mission, the instrument measures temperature profiles from the cloud top (~60 km, p = 0.25 atm.) to a point well within the exosphere (~170 km, p = 10^{-9} atm.). It is therefore capable of investigating the region of CO_2 dissociation near the outer boundary layer and the region containing the ionosphere, as well as the UV cloud region which is the seat of the four-day period dynamic activity. The performance with respect to signal-to-noise and spatial (including vertical) resolution of the instrument has been studied and is very promising. The concept of a zenith scanning method for the elimination of the effects of possible multiple cloud layers on temperature recovery has been evolved. The method makes use of the spinning motion of the Pioneer Spacecraft to obtain stereoscopic coverage of the planet from which information on cloud morphology can be extracted. Extensive numerical testing of the method and further refinement of the Venus experiment concept as a whole, is the principal effort under this task at the time of writing.

PUBLICATIONS

External Publications

1. Farmer, C. B., "The Detection and Mapping of Water Vapor in the Martian Atmosphere," (with D. D. LaPorte) Icarus 16, 36 (1972).

2. Taylor, F. W., "Remote Sounding from Satellites and Space Probes of the Atmospheres of the Earth and Planets" (with J T. Houghton), Reports on Progress in Physics, 26, 827 (1973).

3. Taylor, F. W., "The Abundance of CH_3D and the D/H Ratio in Jupiter" (with R. Beer), Astrophysics J. 179, 309 (1973).

4. Taylor, F. W., "The D/H Ratio in Jupiter" (with R. Beer), Nature, 240, 465 (1972).

5. Taylor, F.W., "The Equilibration of Deuterium in the Jovian Atmosphere" (with R. Beer), Astrophys. J., June 1973, in press.

6. Taylor, F.W., "Preliminary Data on the Optical Properties of Solid Ammonia and Scattering Parameters for Ammonia Cloud Particles," J. Atmos. Sci., June 1973, in press.

7. Taylor, F.W., "Spectral Data for the ν_2 Bands of Ammonia with Applications to Radiative Transfer in the Atmosphere of Jupiter," J. Quant. Spec. and Rad. Trans., in press.

8. Chahine, M.T., "General Relaxation Method for Inverse Solution of the Full Radiative Transfer Equation," J. Atmos. Sci. 29, 741, (1972).

Meeting and Symposia Papers

9. Farmer, C.B., "Infrared Radiometry and Spectroscopy of the Outer Planet Atmospheres," Nato-Advanced Study Institute on Planetary Atmospheres, Istanbul, Turkey, August 22-September 2, 1972.

10. Taylor, F.W., "The Infrared Spectrum of Jupiter and Radiative Transfer Properties of the Clouds" (with G. E. Hunt), American Meteorological Society Conference on Atmospheric Radiation. Fort Collins, Colorado, August 7-9, 1972.

11. Taylor, F.W., "Structure and Properties of the Jovian Clouds." Symposium on "The Dynamics of the Jovian Atmosphere," Lowell Observatory, Flagstaff, Arizona, November 8-10, 1972.

12. Taylor, F.W., "A Review of Present Knowledge of the Structure and Composition of the Jovian Clouds," Laboratory Research Conference on "Astronomy in the 1970's," Jet Propulsion Laboratory, Pasadena, February 23, 1973.

PHOTOCHEMISTRY OF PLANETARY ATMOSPHERES

NASA Work Unit 185-47-72-01-55
JPL 601-47210-0-8280
W. B. DeMore

OBJECTIVE

The primary efforts are directed towards understanding the photochemical factors which determine the equilibrium composition of the Martian atmosphere.

PROGRESS

Role of Water in the Mars Atmosphere

Current Mars aeronomic models invoke the participation of HO_x radicals derived from water to explain important features of the atmosphere, such as stability of CO_2 and ambient ozone concentrations. Such models were first proposed in this laboratory, following our earlier demonstration that CO_3 plays no role in planetary atmospheres. Full utilization of the new chemical models has been hampered, however, by lack of reliable rate data for some of the key reactions of HO_x species. We have developed a novel steady-state approach for conditions simulating the Mars atmosphere. The method involves simultaneous photolysis of CO_2 and H_2O at 1849Å, with photometric measurement of steady-state ozone concentrations as a function of temperature.

Combined with our earlier results on the temperature dependence of CO_2 absorption coefficients, these experiments can provide a realistic

appraisal of the role of water in the Mars atmosphere. However, budget limitations have forced cancellation of this task in mid-FY'73.

PUBLICATIONS

1. DeMore, W. B., "Pressure Dependence and Mechanism of the Reaction of Atomic Oxygen and Carbon Monoxide," J. Phys. Chem. 76, 3527 (1972).

2. DeMore, W. B., and M. Patapoff, "Temperature and Pressure Dependence of CO_2 Extinction Coefficients," J. Geophys. Res. 77, 6291 (1972).

~~D-5~~
D-7

THEORETICAL STUDIES OF PLANETARY ATMOSPHERES

NASA Work Unit 185-47-72-02-55

JPL 601-47220-0-8250

M. Geller

OBJECTIVE

The broad objective is to establish the physical parameters (such as temperature, structure, composition, and absorption altitude profiles, surface elevations, cloud covering, and polarization) that define the atmospheres of the planets. The work unit can be broken down into two study areas. The first area involves the establishment of a broad basis for understanding and interpreting the spectral features of complex planetary atmospheres and for applying these findings towards the design of ground based and spacecraft experiments. The second area involves the development of analytical and numerical techniques for the interpretation of radiance data in terms of physical structures and chemical compositions of planetary atmospheres.

PROGRESS

A detailed theoretical analysis of the A - X transition in OH and OD is being studied. The effects of lambda doubling and rotation-vibration interaction, to allow analysis of high rotational and vibrational states, are being included.

An analytical scheme has been devised for obtaining the true potential energy curves for diatomic molecules from experimental data. Knowledge of these analytical potential energy curves will be used to obtain analytically, vibrational wavefunctions, Franck-Condon factors, and,

was used for recording spectra of the four Stokes' polarization parameters of Venus between 0.8 and 2.7 microns with a resolution of 0.5 cm^{-1} (Cassegrain focus, 154 cm telescope, National Mexican Observatory, Baja California, July 12 and 13, 1972). Preliminary analysis of certain spectral features and of the CO_2 rotational band structure at 6080 and 6200 cm^{-1} has confirmed the existence and variability of spectral polarization. Spectral polarization can be used to probe the deeper cloud layers inaccessible by photopolarimetry.

A joint proposal with the U. of Wisconsin for a net radiative flux experiment on the small probes of the 1977 Pioneer-Venus Multiple Entry Probe Mission has been accepted. Work is in progress for detailed instrumental design and firmer scientific objectives.

A Forward Scattering Method has been developed for determining the size distribution of scattering particles in an aerosol (haze, cloud, fog), its dynamical evolution with time, and its spatial variations. The method uses either spectral or angular data or both; it is independent of the aerosol refractive index and does not postulate the validity of any analytical model of the distribution. A Director's Discretionary Fund Proposal has been secured for developing a particle size spectrometer based on this method.

A Minimization Search Method has been developed for solving inverse problems of single or multiple anisotropic scattering. It has been applied to reconstruct the actual scattering diagram and determine the single scattering albedo of Venus' atmosphere.

A realistic inhomogeneous model of the lower Venusian atmosphere

ultimately, intensities and abundances.

The effects of vibration-rotation interaction on the intensities of rotational lines in the combination bands of Symmetric Molecules of the group C_{3v} were investigated. Intensity formulas for both the parallel combination band $\nu_n + \nu_{n'}$ and perpendicular combination band $\nu_n + \nu_m$ were derived by the method of contact transformation. In these formulas, the effects of vibration-rotation interaction have been taken into account up to first order approximation.

These formulas were used in the analysis of infrared spectra of ammonia. The lines strengths in the combination bands $\nu_1 + \nu_2$ (parallel) and $\nu_2 + \nu_3$ (perpendicular) of ammonia in the region 4130-4570 cm^{-1} as measured by Dr. J. S. Margolis at JPL were fitted to the intensity formulas by a non-linear least-squares program. Intensity parameters for the $\nu_1 + \nu_2$ and $\nu_2 + \nu_3$ bands were obtained, respectively. It was found that the first order formulas were indeed a great improvement over the rigid symmetric top model. However, some anomalies in the observed line strengths were noted. These were probably due to the effects of resonance interactions arising from accidental degeneracy in the upper state energy levels, which were not included in the first order approximation.

The existence of polarization in astronomical spectra (absorption, emission, resonance-fluorescence), and its formation and behavior (with line strength or depth in the atmosphere, and across the planetary disk) have been theoretically predicted. An interferometer-polarimeter using the technique of high-resolution Fourier spectroscopy has been designed and patented. In a joint project with the U. of Arizona, this instrument

has been developed and extended to the Jovian atmosphere. All processes of radiative transfer by cloud particles and gases have been incorporated in order to understand the formation and shape of pressure broadened absorption lines and collision narrowed hydrogen quadrupole lines.

A dual frequency principle has been developed for the determination of complete vertical temperature profiles in cloudy atmospheres from radiance observations alone, without any a priori assumptions related to the expected solution. The dual frequency principal employs to advantage a property in the Planck function of the dependence of intensity on frequency. This property leads to the formulation of an accurate criterion for the selection of cloud-sounding frequencies for the determination of temperature profiles, cloud-top heights, extent of clouds in the fields of view, and surface temperatures from observations made in the presence of as many as three layers of broken clouds. The method is currently being extended for the treatment of the case of clouds with spectrally dependent characteristics.

The general relaxation method developed earlier for inverse solution of the full radiative transfer equation, for the determination of all atmospheric parameters which appear as functions or functionals in the integrand, is being extended and applied to the determination of size distributions of particles from optical scattering measurements.

During the past year the relaxation method was applied by the Goddard Institute for Space Studies, with cooperation from JPL, for the determination of temperature profiles from the ITOS VTPR data, and was used by GFSC for the analysis of Mariner 9 IRIS data.

PUBLICATIONS

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Kwan, Y. Y., "Intensities of Rotational Lines in Combination Bands for Axially Symmetric Molecules of the Group C_{3v}," Ohio State Symp., Columbus, Ohio, June 8-12, 1973

Kwan, Y. Y., "Measurement and Theoretical Analysis of $\nu_1 + \nu_3$ and $\nu_2 + \nu_3$ bands of NH_3," Ohio State Symp., Columbus, Ohio, June 8-12, 1973 (with J. Margolis)

~~GMFT~~ D-8

MICROWAVE SPECTRAL STUDIES

NASA Work Unit 185-47-72-03-55

JPL 601-47230-0-8250

R. Poynter

OBJECTIVE

This task's objective is to use microwave spectroscopic techniques and results to predict the behavior and structural composition of planetary atmospheres, and to provide the required background for planetary observations, and spaceflight studies, by providing the relevant laboratory microwave spectroscopic information required for the planning of observations and the interpretation of the results.

PROGRESS

1) Deep atmospheric models were constructed for Jupiter and Saturn. The Jupiter model was extended to include the upper atmosphere.

2) The radiative transfer computations of the microwave spectra of Jupiter were modified to include the upper atmospheric region. The far infra red rotational line effects upon the microwave spectrum have been analyzed but have not been included in the RT computations. Other published results were shown to be in error.

3) The microwave spectrum of the v = 0001 vibrational state of ammonia has been analyzed for both the ^{14}N and ^{15}N isotopic species. Application of these results to the RT problem were started.

4) Preliminary experimental work was started on ultra high pressure absorption measurements for NH_3 - H_2 mixtures. This work had been planned to confirm limited published results and extend the measurements to cover the mixture ranges expected on Jupiter.

5) All the above work was terminated in Jan. 1973 by the program funding cuts. The main results have been very useful for interpreting the very high quality planetary radio observational data, recently obtained in other parts of this program. These results have led to a significantly improved model of the Jovian atmosphere, which is of particular importance to any flyby or entry probe mission.

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External Publications

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~~D-6~~
D-9

VOLATILE EVOLUTION

NASA Work Unit 185-47-72-04-55
JPL 601-47240-0-8260

F. P. Fanale

OBJECTIVE

The objective of the volatile evolution task is to gain new insights into the origin and history of solar system volatiles and planetary atmospheres. Specific areas emphasized during the last year were (1) Identification of the mechanism by which volatiles that were uncondensed at the time of separation of gas and dust in the pre-planetary nebula (e.g., primordial rare gases) were incorporated into and retained by the pre-planetary dust. (2) Determination of the causes of differences between the bulk volatile contents of planetary objects and the variation in bulk volatile content of pre-planetary dust as a function of heliocentric distance. (3) Identification of the role of regolith adsorption in controlling the H_2O and CO_2 content of the martian atmosphere and polar caps as well as its role as a permanent sink for martian surface volatiles. (4) Determination of the formation interval of the earth and the time history of earth degassing.

PROGRESS

(1) Laboratory studies of the visible and near infrared reflectance of a suite of carbonaceous chondrites and simulated carbonaceous chondrites have allowed comparison to visible and (very recently) infrared reflectivities of main belt asteroids. These studies have shown that, among cosmically important materials (including iron meteorites, enstatite chondrites, basaltic glasses,

etc.), carbonaceous chondrites provide the best match to some low-albedo, relatively featureless asteroid curves. Moreover, other asteroids are best matched by carbonaceous chondritic materials with an even larger opaque carbonaceous component than even the most primitive C1 meteorites. A manuscript entitled "Optical Properties of Carbonaceous Chondrites: Relationship to Asteroids" has been prepared and submitted to the Journal of Geophysical Research.

(2) A study of water and rare gas adsorption in the Orgueil meteorite has been completed. Adsorption has been the most important process in determining the volatile content of this unique object and interlayer adsorption on montmorillonite is the most important component. During the last phases of planetary accretion, dispersed material, similar to the matrix material of Orgueil, comprised the bulk of the dispersed silicate in the outer solar system (asteroid belt and beyond) and presented a BET surface area of over 100 m^2/g. Adsorption was the major means by which volatiles still uncondensed at the time of gas-dust separation were incorporated into planetary objects. A manuscript entitled "Surface Properties of the Orgueil Meteorite: Implications for the History of Solar System Volatiles" has recently been submitted to Geochimica et Cosmochimica Acta.

(3) A study of the CO_2 and H_2O adsorption equilibrium between the martian atmosphere and regolith has been completed. The equilibria were studied under realistic martian surface conditions. Results show the total amount of H_2O and CO_2 stored in the adsorbed phase must be 10^5 - 10^6 and 10-100 times the respective atmospheric inventories of these volatiles in order for the regolith to be in physical equilibrium with the atmosphere. We have estimated the exchange adsorbed regolith H_2O and CO_2 and the atmosphere-cap system as a

function of surface insolation for local diurnal variations, regional seasonal variations, and 10^4 - 10^5 year global variations caused by variations in orbital parameters. A manuscript - "The Martian Regolith Adsorption Buffer" - has been prepared for submission to Nature.

(4) We have devised and constructed an ion-counting, rare gas, mass spectrometer offering many advantages over conventional, static, rare gas, mass spectrometers. The instrument will be used to determine the content and isotopic composition of Xe in the earth's lithosphere. This will allow determination of the formation interval of the earth and definition of its early degassing history. The ion counting digital integration system has been operational for several months and has generally fulfilled our expectations in offering great advantages in convenience and objectivity of data processing. But three problems have prevented us from realizing its full potential: (1) The noise level is much greater than predicted. This problem has recently been alleviated by modification of electronic components and by coating the exterior of the tube. Additional lowering of the noise may be affected by cooling the electron multiplier. (2) At present all channels in the vicinity of Xe are scanned. We intend to improve our signal: noise ratio by jump scanning only key background and peak top channels. (3) We intend to improve the chemical cleanup procedure for organic background contamination. These improvements will allow us to extend accurate isotopic measurements to rocks containing $< 10^{-12}$ ccstp/g Xe and Kr.

D-7
D-10

ELECTRON IONIZATION AND COLLISIONS IN PLANETARY ATMOSPHERES

NASA Work Unit 185-47-72-05-55
JPL 601-47250-0-8280
S. Trajmar

OBJECTIVE

The general objective is to study and understand electron molecule (atom) collision processes occurring in planetary atmospheres. Specifically, the objective is to determine cross sections for these processes and to utilize electron impact spectroscopy for determining the energy levels of molecules that are not detectable by means of optical spectroscopy.

PROGRESS

Polyatomic Molecules

A significant break-through has been achieved in connection with the observation and identification of the electronic states of polyatomic molecules. The energy level scheme and potential energy surfaces have to be known to apply conventional spectroscopical methods for polyatomic molecules and to interpret their photochemistry. In recent years it became obvious that there was no hope of getting this information by the methods of optical spectroscopy (because of the extreme complexity of spectra). For such an important molecule as CO_2 not one single electronic transition has been analyzed or positively identified. The present break-through became possible by the utilization of new experimental

and theoretical methods. The construction and testing of the Very Low Energy Electron Impact Spectrometer has been completed and measurements at very low impact energies and high scattering angles became possible. The electron impact excitation spectra of molecules changes drastically with energy and angle at low impact energies and certain transitions dominate the spectrum under some conditions while under other conditions their contribution to the spectrum is negligible. By taking advantage of this situation one can decipher the complex spectra of polyatomic molecules. There are still many ambiguities in interpreting the experimental spectra and theoretical help is needed. An ab-initio multi-configurational interaction program has been generated which for the first time can predict the excited electronic levels of polyatomic molecules to within about 0.2 eV. The experimental progress was achieved in collaboration with Dr. R. I. Hall, RRA (University of Paris) and the theoretical progress with Dr. N. Winter, RRA. Utilizing these methods, H_2O, CO_2, and N_2O have been investigated and a large body of new findings have been accumulated. Several papers have been submitted for publication and the evaluation of the data will continue during the next fiscal year.

Diatomic Molecules

Investigations of N_2, O_2, CO, continued utilizing both the High Resolution Electron Impact Spectrometer and the Very Low Energy Electron Impact Spectrometer. Several papers have been published along this line and other papers are in preparation.

Rare Gases

He and Xe have been investigated and the results have been published or are in preparation for publication.

Instrumental Developments and New Techniques

The target beam source for the Very Low Energy Electron Impact Spectrometer has been modified to be able to study metastable species and free radicals. Work on O_2 ($a^1\Delta g$) metastable is in progress.

The optical spectrograph and the coincidence circuitry for the High Resolution Electron Impact Spectrometer has been designed, fabrication and assembly are in progress to carry out electron-photon coincidence measurements (life time, high resolution optical excitation functions).

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12. S. Trajmar, "Differential and Integral Cross Sections for the Excitation of the 2^1S, 2^3S, and 2^3P States of He by Electron Impact at 29.6 eV and 40.1 eV." Accepted by Phys. Rev.

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1. A. Chutjian, D. C. Cartwright and S. Trajmar, "Identification of the $W^3\Delta_u$, $w^1\Delta_u$, $B'\,^3\Sigma_u^-$, and $a'\,^1\Sigma_u^-$ States of N_2 by Electron Impact Spectroscopy, Div. of Electron and Atomic Physics, Am. Phys. Soc. Meeting, Palo Alto, Nov. 29-Dec. 1, (1972) Bull. Am. Phys. Soc. 17, 1139 (1972).

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ION CHEMISTRY

NASA Work Unit 185-47-72-10-55
JPL 601-47251-0-8280
W. T. Huntress, Jr.

OBJECTIVE

The broad objective of this work is to study the ion chemistry of planetary atmospheres: to identify the reactions which occur between ions and neutrals in the atmosphere and to measure the rate constants for these reactions. The work has been specifically directed towards the ion chemistry occurring in reducing atmospheres of near-solar composition.

PROGRESS

Instrumental

In the past year the ion cyclotron resonance (ICR) spectrometer has been extensively modified for operation as an ion trap in which ions are formed and stored, and the mass spectrum of the ions can be taken as a function of time. This mode of operation allows for very accurate measurement of absolute rate constants for ion-molecule reactions. A new detector has also been developed which allows for detection of electrons and for more efficient detection of low mass ions. These two accomplishments represent a major advance in laboratory instrumentation for the study of gas phase ion-neutral reactions.

Ion-Molecule Reactions

The developments made in ICR spectrometry in this laboratory have made possible for the first time: 1) the complete identification of all ion-molecule reactions occurring in complex gases and mixtures of gases at thermal ion-kinetic energies, and 2) accurate measurement of their rate constants. While space prohibits a complete listing of results obtained, a few of the highlights are described for the various gases studied.

H_2 The reaction $H_2^+ + H_2 \longrightarrow H_3^+ + H$ is one of the principal processes controlling the ion and electron densities in the upper atmosphere of Jupiter and Saturn. The rate constant for this reaction is more than four times larger than previously used in all ionospheric models to date.

CH_4 The rate constants for the reactions of CH_3^+, CH_2^+ and CH^+ ions which yield $C_2H_5^+$, $C_2H_4^+$, and $C_2H_3^+$ product ions have been measured. These reactions lead to the production of ethylene and acetylene in the lower atmosphere of Jupiter and in the atmospheres of the Jovian moons.

NH_3 Accurate rate constants for reactions in ammonia have been obtained for the first time, and reactions excited NH_3^+ ions have been identified.

H_2O A previously unsuspected reaction of OH^+ ions has been identified, and accurate rate constants obtained.

H_2S Several condensation reactions have been identified which produce diatomic sulfur ions including S_2^+, S_2H^+ and $S_2H_2^+$. These latter ions may lead to the formation of polyatomic sulfur compounds in the Jovian atmosphere, which in turn may contribute to the colors in the cloud bands.

CH_4-NH_3 The reaction $CH_3^+ + NH_3 \longrightarrow CH_2NH_2^+ + H_2$ leads to a rapid route for the production of HCN by ionization processes in CH_4-NH_3 mixtures. The mechanism by which HCN is produced by energetic processes in CH_4-NH_3 mixtures has previously been mostly a matter of speculation. The identified process most certainly will be important in planetary atmospheres of near-solar composition.

CH_4-H_2O The reaction $CH_2^+ + H_2O \longrightarrow CH_2OH^+ + H_2$ leads to a rapid route for the production of formaldehyde in CH_4-H_2O mixtures. This process, together with the aforementioned process in CH_4-NH_3 mixtures, lead to the production of the two most important precursors for the synthesis of organic molecules in primordial atmospheres.

CH_4-H_2S Several reactions in these mixtures lead to the production of CH_2SH^+. Further processes involving this ion can lead to thio-formaldehyde, an important precursor in abiogenic synthesis for the formation of sulfur peptides.

NH_3-H_2S Several reactions in these mixtures lead to the production of NH_2S^+, which may be an important intermediate ion for the formation of chromophores and abiogenic precursors containing N-S bonds.

Dissociative Photoionization of H_2

In addition to ICR experiments, we have used a photoionization mass spectrometer in our laboratory to measure the cross-section for the formation of protons by dissociative photoionization of hydrogen at 584Å. This process has previously been ignored as a source of protons

in the Jovian ionosphere. Our work has shown it to be important at heights where the peak ionization rates occur.

PUBLICATIONS

Meetings and Symposia Papers

1) W. T. Huntress, Jr., "Ion Chemistry of Planetary Atmospheres", banquet address, 1973 Los Angeles Meeting of the Junior Section of the American Chemical Society, April 1973.

2) J. Laudenslager and W. T. Huntress, Jr., "Ion-Molecule Reactions in CH_4, NH_3, H_2O, H_2S and Various of their Mixtures", 21st Annual Meeting of the American Society for Mass Spectrometry, San Francisco, May 20-24, 1973.

3) L. Theard and W. T. Huntress, Jr., "Reactions of Ions in Hydrogen", 21st Annual Meeting of the American Society for Mass Spectrometry, San Francisco, May 20-24, 1973.

Internal Publications

1) R. F. Pinnizotto, Jr., (W. T. Huntress, Jr., research advisor) "An Ion-Cyclotron Resonance Study of Some Ion-Molecule Reactions in Primordial Atmospheres", Honors Thesis for the B.S. degree in Chemistry, California Institute of Technology.

External Publications

1) W. T. Huntress, Jr., and R. F. Pinnizotto, Jr., "Product Distributions and Rate Constants for Ion-Molecule Reactions in Water, Hydrogen-Sulfide, Ammonia and Methane", accepted by J. Chem. Phys.

2) J. B. Laudenslager and W. T. Huntress, Jr., "Ion-Molecule Reactions in Mixtures of Hydrogen Sulfide with Water and Ammonia", accepted by Int. J. Mass. Spec. Ion Phys.

3) W. T. Huntress, Jr. and W. T. Simms, "A New Ion and Electron Detector for Ion Cyclotron Resonance Spectroscopy", Rev. Sci. Instr., appears Aug. 1973.

4) W. T. Huntress, Jr., R. F. Pinnizotto and J. B. Laudenslager, "Ion-Molecule Reactions in Mixtures of Methane with Water, Hydrogen-Sulfide and Ammonia", J. Am. Chem. Soc., appears July 1973.

5) W. T. Huntress, Jr., "On Ion-Molecule Reactions in Ammonia", Int. J. Mass Spec. Ion Phys., appears July 1973.

6) W. T. Huntress, Jr., et al., "Cross-Section for the Dissociative Photoionization of Hydrogen by 584Å Radiation: The Formation of Protons in the Jovian Ionosphere", accepted by Planetary and Space Science.

~~D-9~~
D-12

PLANETARY FROST STUDIES

NASA Work Unit 185-50-71-05-55

JPL 601-57150-0-8260

J. E. Conel

OBJECTIVE

Experimental and theoretical techniques for measuring the complex indices of refraction of methane and ammonia ices are under development. These fundamental physical data will be of importance in outer planet atmospheric radiative transfer calculations, in calculations dealing with reflection properties of outer planet satellite surfaces, in reflectance studies of the Martian polar caps (wherein CO_2 ice would be considered) and possibly in cometary spectroscopic studies. For experimental reasons, initial efforts will be confined to the near-infrared region of the spectrum.

PROGRESS

A comprehensive survey of the literature was conducted to obtain any previous data on optical properties of ices of concern here. No such data were found.

The program has divided itself naturally into experimental and theoretical parts. We are adopting experimental procedures for growth of polycrystalline ice samples (isotropic optically as single and polycrystals) from similar procedures developed for high-pressure equation of state work on solid hydrogen. It is fortunate in our case however, that we are able to work at or above liquid nitrogen temperatures.

To achieve large optical depths and adequate surface area, relatively large volumes of ice (~ 200 cm^3) are required. Optically flat surfaces are to be obtained by using polished windows (CaF_2) against which the ice will be grown. The ice chambers, windows, cryogenic plumbing, and stainless steel vacuum system are all fabricated or are under development. It is anticipated that preliminary ice-growing experiments will begin soon. Initially we will work with argon, and silica glass windows to iron out difficulties in the technology. This appears to be the most desirable procedure, as methane and ammonia are both noxious gases, and we anticipate that window breakage will probably occur in initial experiments.

Major portions of the spectroscopic system have been ordered, InSb detector, dewar, and pre-amplifier (Santa Barbara Research), synchronous lock-in amplifier (Princeton Applied Research), and grating (Bausch and Lomb). We have acquired a PDP-8 computer from sources at JPL for the data reduction system. This major benefit will allow us to process raw reflectance data without resort to larger computing machines and intermediate hand manipulation of the data.

Preliminary designs for the overall optical system have been completed. It appears theoretically simpler to work with reflectance data taken at normal incidence to avoid effects of polarization at interfaces; but this arrangement requires use of a beam-splitter which introduces large energy losses in the optical train. Design of the beam-splitter is under study. As presently constituted the optical arrangement will consist of light source, chopper, monochrometer, collimator, beam splitter, vacuum system with CaF_2 window, ice sample and internal (to the vacuum chamber) reference. We will work in single beam, obtaining the "composite" sample reflectance by comparison between ice and internal standard refereace. These two will be interchanged sequentially

and aligned in the beam by mechanical feed-throughs in the vacuum chamber walls.

A subsidiary program for determining the optical constant of CaF_2 at or near liquid nitrogen temperatures will be undertaken, as these data will not be available for our experimental conditions.

Several possible approaches to the theoretical problem of determining refractive indices of ice from the composite system window-ice are being explored. These problems are currently being studied by Professor George Jiracek of the University of New Mexico. Pending detailed error analysis, a feasible scheme is to utilize the so-called Kramers-Krönig method to derive phase information from the amplitude reflection coefficient of the composite medium. The experimental problem of having measurements over only a finite band-width may be overcome using analytical techniques developed by Andermann, Caron, and Dows (1965). Then, expressions for the effective impedence of the composite medium may be written down from standard works on electromagnetic theory, and these used to obtain the complex reflection coefficient. An analytic separation of the resultant expression is possible giving the real and imaginary parts of the complex index in terms of an expression involving the real and imaginary parts of the effective impedence.

PUBLICATIONS

Meeting and Symposia Papers

Goetz, A. F. H., J. E. Conel, and T. V. Johnson, Planetary Frost Studies (Abstract presented at Annual PPPI Meeting, Ames Research Center, 1973).

D-13

SURFACE ANALYSIS BY COMBINED ALPHA SCATTERING/ X-RAY FLUORESCENCE

NASA Work Unit 185-50-71-14-55
JPL 601-57120-0-8280
E. J. Franzgrote

OBJECTIVE

The objective of this task is to develop techniques of surface analysis that may be used to determine the composition of the surface and atmosphere of Mars on a Mars-lander mission. The two techniques being studied are (1) alpha-particle scattering, and (2) excitation of X-rays by alpha-particle bombardment.

PROGRESS

It was shown in the past year that the stringent environmental and weight restrictions of a Mars-lander mission can be met using the newly-developed high-purity germanium detectors cooled by a miniature open-cycle Joule-Thomson cryostat. Two germanium detectors subjected to heat-sterilization at 135° C survived with no change in resolution. To obtain early experimental data using germanium, a standard liquid-nitrogen-cooled germanium detector has been incorporated in the miniaturized alpha-scattering instrument at the University of Chicago. Some data have now been obtained with this system and they are similar in quality to X-ray data obtained with a silicon detector in earlier studies at JPL except at energies below 3 keV. At the lower energies, the preliminary data indicate that the silicon detector is superior, but even if later data with other detectors confirm this, the low-energy region is already well covered by the alpha-scattering mode. Data obtained to date are being used in a fundamental study of the production of X-rays by alpha-particle bombardment. JPL participation in this data analysis has contributed to an understanding of the spectra from a series of potassium compounds by showing that partial absorption of the potassium X-rays

is involved (contrary to an earlier assumption made in the analysis of the α/X-ray data obtained with the JPL silicon detector). The X-ray responses from a series of 12 potassium compounds, corrected for absorption, give a standard deviation from a straight-line relationship of less than 9%.

An X-ray detector system closer to flight configuration and designed to replace the liquid-nitrogen-cooled system in tests at the University of Chicago has now been assembled. This incorporates a miniature Joule-Thompson cooler and a high-purity germanium detector. Discussions with personnel of the Naval facility at China Lake, California, have resulted in identification of auxiliary equipment needed to operate the Joule-Thomson cryostat. Plans have been made for the testing of this system using high-purity argon gas as the coolant and Fe^{55} as a calibration source.

PUBLICATIONS

None.

~~GMTT~~
D-14

MARS RADAR PROFILING AND SOUNDING STUDY

NASA Work Unit 185-50-71-17-00

JPL 601-57117-0-8230

W. E. Brown, Jr.

OBJECTIVE

Radar system parameters and tradeoffs will be determined for a Mars orbiting experiment. The basic techniques used to design the Lunar Sounder Experiment (Apollo 17) will be used. Geomorphology requirements on the radar will be included in the radar design iterations.

PROGRESS

Computer programs were written and verified to determine system response of different radar system configurations to various surface models. This task, however, was canceled before the program could be exercised to determine system characteristics.

PLANNED ACTIVITIES

None.

PUBLICATIONS

None.

~~D-10~~
D-15

SILICON CAMERA DEVELOPMENT

NASA WORK UNIT 185-50-71-18-55

JPL 601-57118-0-8210

W. M. PORTER

OBJECTIVE

The objective of this work is to develop advanced imaging concepts which will yield low-cost, long-life imaging instruments for use on outer planet missions beginning in 1979. To meet this objective, development of feasibility model cameras utilizing new sensors has been undertaken. The initial development was directed toward silicon vidicons. Subsequent activities will be directed toward solid state cameras using charge coupled sensors. This is a long-term program which will start in FY '74, with the objective of developing a low-cost, general-purpose planetary camera system. Simplicity, long life, and high performance are also inherent characteristics of the charge coupled sensor approach.

PROGRESS

The feasibility model of the silicon vidicon camera has been built and evaluated, which completes the work in this area. The following activities, under the joint sponsorship of the NASA 185 and 186 Programs, have taken place.

Functional Design

Functional requirements were established for the camera based on the following objectives:

1. To design, manufacture, and test a silicon vidicon camera capable of slow-scan operation and determine its feasibility for space flight applications.
2. To determine the packaging requirements of the silicon vidicon which incorporates the thermal, mechanical, optical, and electrical considerations imposed by expected space flight mission constraints.
3. To gain experience and expertise by actual operation of the camera under simulated mission environmental conditions.

Based on these requirements, an imaging system incorporating a Mariner TV modified to operate with and to cool a silicon vidicon was blocked out.

Conceptual Design

The general approach to the design was to modify a Mariner '71 Imaging System to operate with a silicon vidicon. This was done so as to enable available resources to be applied to the problems which are unique to the operation of a silicon vidicon in a flight-configured camera. The design concentrated in three (3) basic areas: cooling of the vidicon, electrical circuitry necessary for the operation of the vidicon, and modification of the Mariner support equipment to operate the completed silicon vidicon camera.

The general design approach decided upon for the camera head was to thermally isolate the vidicon from the rest of the structure and cool only it. This represents a departure from earlier concepts which would have cooled all or most of the camera head. While the general approach decided upon appeared the most difficult of the two to implement, it held the promise of requiring a much smaller radiator for cooling and was chosen for this reason.

Three (3) different concepts were considered for cooling the vidicon. The concept which was developed is to isolate the vidicon and a cold front plate assembly from the camera chassis by a large diameter insulating cylinder.

The other concepts which were considered included supporting the vidicon by an insulator from a warm front plate and supporting the vidicon from the inside bore of the coil assembly. In choosing which concept to use, preliminary thermal and structural analyses were made of the different configurations. Additionally, consideration was given to constraints which each configuration might impose upon the electrical design.

In performing the conceptual design, a thermal analysis was carried out considering the heat leaks presented by the candidate designs, probable radiator sizes for each of the designs, and the need for bench operation. The predicted

radiator size for the chosen design was 278 cm^2. Radiator sizes for the other candidate designs were predicted as 214 cm^2 and 242 cm^2. The design chosen for development was picked after careful consideration of the relative ease with which each design might be implemented as hardware.

Detailed Design

Close attention was paid to the thermal aspects of the detailed design. The concept chosen to be realized was modeled for a thermal analysis computer program and simulations were run as the details of the design were developed. This allowed for the optimization of the camera head in terms of minimizing heat leaks.

The structural aspects of the design considered survival of vibration levels equivalent to a Mariner launch and thermal stresses and displacements resulting from cooling the vidicon.

The electrical design considered the necessary timing changes to the Mariner support equipment and prototype electronics as well as the new circuitry required to operate the silicon vidicon. Worst case circuit design techniques were used to ensure operation over the full temperature range as well as to ensure operation independent of expected component parameter changes.

New circuitry included a hybrid preamp having a 6 db higher signal-to-noise ratio than the replaced Mariner preamp. The improvement in signal-to-noise ratio in the Mariner electronics was made necessary by the fact that the signal current of the silicon vidicon is lower than that for which the electronics were originally designed.

Environmental Test

Testing of the camera concentrated on its ability to operate under space flight conditions and on its ability to survive a rocket launch. No serious effort was undertaken to evaluate the quality of its pictures since the vidicon was evaluated separately under another program.

The first test performance on the camera was to verify its ability to operate on the bench. This was done by evaporating LN_2 in the heat exchanger which attaches to the radiator. The radiator was covered with 2.5 cm of polystyrene foam and the camera was purged with dry nitrogen. No trouble was encountered in lowering the vidicon faceplate temperature to the required -40°C.

The camera was first tested in thermal vacuum with a simulated scan platform temperature of +35°C. This resulted in a vidicon faceplate temperature of -58°C against a designed for temperature of -40°C and a predicted temperature of -65°C for the conditions actually simulated. Subsequent analysis of the temperature data taken shows the heat leak into the camera front plate to be somewhat larger than predicted, possibly caused by degraded low emissivity surfaces.

The initial thermal design for the camera predicted a minimum temperature below -70°C for the vidicon faceplate assuming low spacecraft temperature. Because the structural design considered this to be the minimum temperature, part of the radiator was masked off before proceeding with the testing. This was done as a precaution against overstressing the vidicon or its supporting structure caused by temperatures below -70°C. On the basis of the data taken, all but 130 square centimeters of the radiator were covered with aluminum tape to hold the vidicon to a predicted temperature of -61°C.

After masking off part of the radiator, a second test was run at a simulated scan platform temperature of -20°C. The vidicon faceplate reached a predicted temperature of -60°C.

Vibration testing consisted of shaking the camera along all three axes. First in a .5 grms sine sweep from 30 to 2000 Hz at 2 oct/min. Following this, the camera was tested to the flight acceptance and type approval levels which were established as typical of future Mariner launches. In both cases, the sine sweep preceeded the random vibration test. All three axes were tested at the FA levels before proceeding to the TA levels.

The flight acceptance sinusoidal vibration test consisted of sweeping per the specified sinusoidal amplitude levels from the lowest frequency to the highest frequency and back to the lowest frequency at a logarithmic rate of 4 octaves/min. The type approval test was similar with a sweep rate of 2 octaves/min. The flight acceptance random vibration test levels were applied for one minute on each axis. The type approval test was similar, applying the test levels for 5 minutes on each axis. The random vibrations had a gaussian amplitude distribution except that instantaneous peak amplitudes of greater than 3 sigma were supressed.

The camera survived all vibration testing intact with the exception that a rear fiberglass support for the radiator broke during testing at the TA levels. This was considered to be of little consequence, as this part could easily be made stronger without compromising the overall design. The limit load used for the design of the vidicon support implies an acceleration at the free end of 450 g lateral and 300 g axial. The corresponding acceleration observed at flight acceptance test level was 176 g at 300 cps and 200 g at 600 cps.

PLANS FOR FY '74

In 1974, it is planned to switch investigation to the utilization of solid state charge coupled imaging devices and associated electronics. To take advantage of the current availability of line array devices, a line scan camera will be implemented first. This will be done such that there is maximum applicability to the area array camera planned for the following fiscal year.

The following objectives are planned for FY '74:

1. Study of line array sensors and a determination of their status.
2. Line array CCD sensor acquisition and testing.
3. Functional design of a line array camera emphasizing simplicity in both the instrument and the instrument-spacecraft interface.
4. Definition of required support equipment.
5. Camera detailed design.

~~D-11~~
D-16

COMPUTER CARTOGRAPHICS

NASA Work Unit 185-50-71-19-55
JPL 601-57119-0-8240
W. B. Green

OBJECTIVES

The objectives of this task were (1) development and documentation of computer programs to perform cartographic projections of images returned from the MVM73 mission, and (2) specification of requirements for the MVM73 Television Experiment Supplementary Experiment Data Record. Both of these objectives have been achieved, despite a small reduction in funding available for this task during the year.

PROGRESS

MAP2 Program Development

At the start of this task, the MAP2 program at the Image Processing Laboratory was being utilized to perform cartographic projection of Mariner 9 images. The program was specifically written for Mariner 9 applications, and modifications were necessary to allow projection of images of the earth, the moon, Venus and Mercury so that the program could be applied during the Mariner Venus Mercury cartography activities. It was planned to devote the majority of the resources available under this task to the program modification activity.

The program was modified as needed, and the task objective has been achieved — it will be possible to perform cartographic projection of images returned from the MVM mission. The program modifications were performed in such a way as to generalize the program. At this point, use of the program for future missions requires only a small effort to add camera parameters, planetary constants, and the capability to read either geodetic control points

or project-generated supplementary data records for each individual image to be processed. This is the last time that a major coding effort will be required to perform cartographic projections of individual planetary images.

The program can perform four types of cartographic projection: orthographic, stereographic, mercator and lambert conformal. The program was verified using Mariner 9 imagery. Twenty-four Mariner 9 images were selected and cartographically projected using the new MAP2 program. The results were then compared (using digital techniques) with results obtained using the old version of the program and included in the final cartographic products generated as part of the Mariner 9 project activity. Exact agreement between the two projected versions of each of the twenty-four selected images verified program performance.

In addition to software modification, close contact was maintained with the MVM73 Imaging Team. Dr. Newell Trask served as a technical monitor of this activity for the Imaging Team. With this assistance, the planetary constants to be used for Venus and Mercury were determined and built into the program. In addition, other details (e.g., exact scales factors to be used for Venus and Mercury imagery as a function of approach distance, etc.) were determined early, in conjunction with the Imaging Team, thus allowing efficient processing of flight imagery from the MVM mission.

Other Activity

The negotiation of the content and format of the MVM73 Television Experiment Supplementary Experiment Data Record (the SEDR) with the MVM73 project was a recognized part of this task. It has been possible to develop an acceptable format that requires a minimum of computer processing to generate. All quantities required for cartographic projections will be included in the TV SEDR to a precision sufficient to allow accurate computer processing.

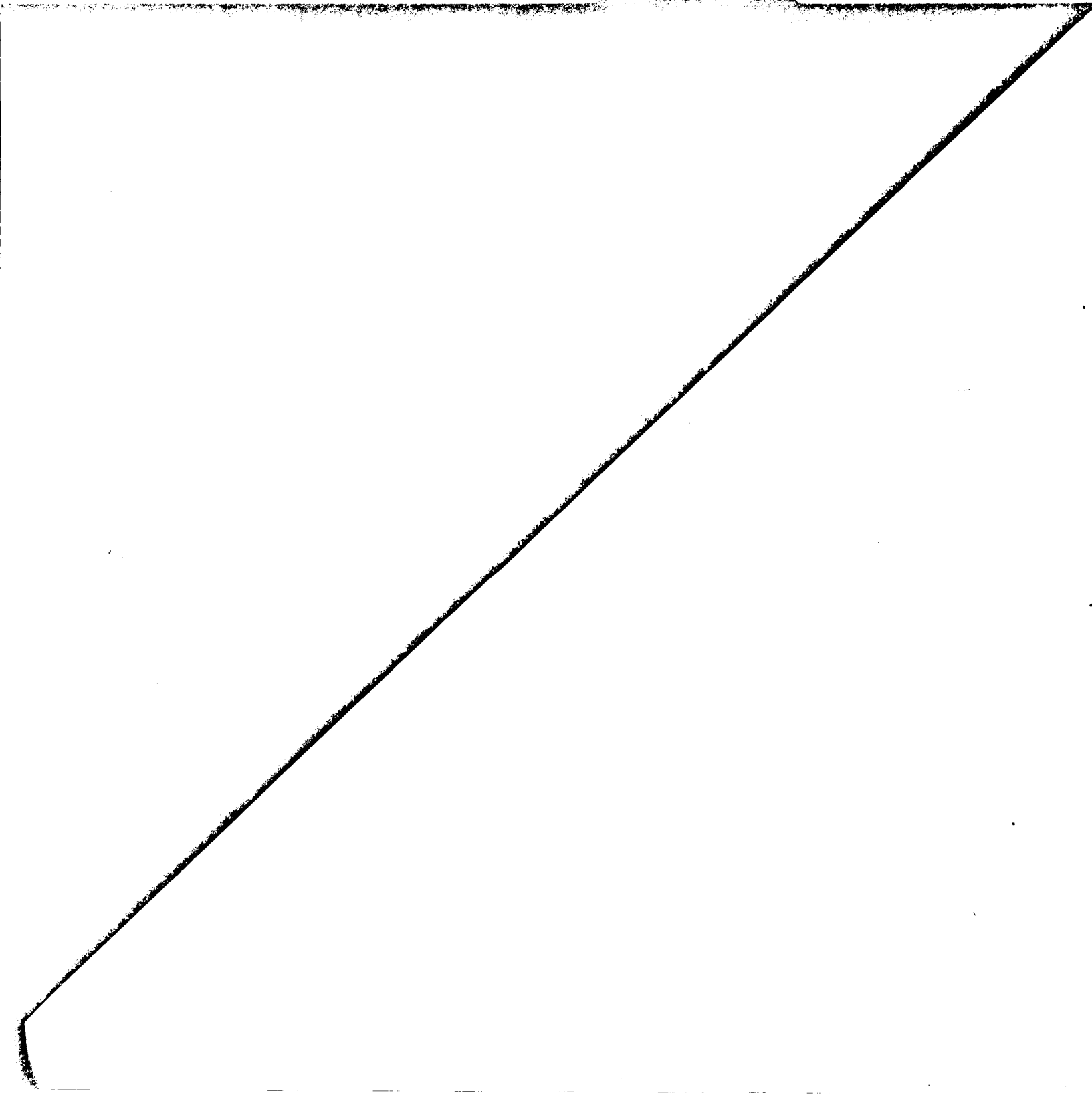
Here again, early resolution of these details will enable efficient production of cartographic products from Venus and Mercury. The negotiation of the SEDR format for the quarter frames was also conducted with the Imaging Team and the Project.

Two other activities were conducted as part of this task. The first was participation in the Planetology Program Principal Investigators' Meeting at the Ames Research Center in January, 1973. At that meeting, technical contact was made with many other Planetology Program Principal Investigators, and a fruitful exchange of views occurred; W. Green presented a status report on the Cartographics task.

The second activity was not anticipated, but occurred following the January Principal Investigators' meeting. As a result of that meeting, PI's had a name and phone number at JPL to utilize for assistance in clarifying the set of Mariner 9 data products that they received throughout the year. Based on technical contacts made at the meeting, several PI's contacted JPL to obtain clarification regarding computer processing applied to Mariner 9 images and the format and content of the output products. In particular, it was possible to provide Dr. Henry Faul and Dr. John Guest with high quality copies of Mariner 9 imagery required for their research activities.

PUBLICATIONS

None.



D-17

ADVANCED MAGNETOMETER

NASA Work Units 188-36-55-01-55
188-36-55-03-55
JPL 603-35111-0-8280
603-35110-0-8230
E. J. Smith

OBJECTIVE

The primary object of this task is to develop the vector helium magnetometer for use in deep space missions, where extremely weak interplanetary or interstellar fields are to be measured, and where intense planetary fields may also be encountered. The major requirements for such a magnetometer are improved sensitivity, stability, dynamic range and reliability.

PROGRESS

The testing and development of sensor components continued. A careful study of helium lamps was carried out to determine the effect of lamp diameter, or equivalently the characteristic diffusion length of the discharge, on various operational parameters. The ignition potential was found to increase rapidly with decreasing lamp diameter as predicted qualitatively by theory. The minimum potential required to sustain the glow discharge was also determined for various lamp diameters. Finally, the sustaining potential required to produce a given signal level was also measured as a function of lamp diameter. The resulting parametric curves will enable a design trade-off to be made between the operating power required, the voltage required for ignition and safeguards against having the lamp extinguish as a result of changing power levels.

The lamp reservoir, which prevents a reduction in pressure owing to permeation of the helium through the glass walls, was changed from a sphere to a cylinder. A helical coil was wound on the reservoir and tuned to the radio frequency (rf) used to produce the discharge. By making the coil a part of the boom cable impedance matching network, it became possible to ignite the reservoir using low voltage rf power. This eliminated the need for large ignition potentials and allows the ignition circuit used on previous Mariner and Pioneer magnetometers to be deleted in future designs.

The preceding lamp studies led to the development of an on-Lab capability to fabricate and fill helium lamps and cells in a rapid and efficient manner. A system was developed to fill lamps and cells in the laboratory at atmospheric pressure. Contaminants were reduced to a low level by maintaining an rf discharge in the lamp or cell for approximately one day prior to the final filling.

The Mariner magnetometer used a lens and the Pioneer magnetometer used a parabolic reflector for collimation. Measurements of both the signal and the signal-to-noise ratio were carried out with and without the reflector and it was confirmed that the principle advantage of the reflector is a major increase in signal level with little increase or decrease in sensitivity. The engineering advantages of operating on large signals dictate the continued used of a reflector in future designs.

An ongoing study of screening procedures to be used with operating lamps and cells was completed and an internal report was prepared. The

performance parameters to be measured and the means of making measurements have been established. This makes it possible to set realistic tolerance levels and to determine if a given lamp or cell will perform acceptably before it is installed into the sensor.

System testing also continued using various magnetometer sensors. A major area of investigation continued to be changes of magnetometer offsets as a result of changes in various parameters. Alignment effects were quanitatively determined by rotating and translating both the lead sulfide (PbS) and the silicon (Si) detectors. As anticipated, the large area Si detector was found to be much less sensitive to such changes than the smaller PbS detector. The alignment of the lamp in the reflector was also studied and found to affect the magnetometer offset, however, rather gross changes in alignment were required before the effect became significant. All such dependences were carefully measured quanitatively with a view to establishing design specifications that will restrict any offset variations to tolerable levels.

Comparative offset data were obtained for both the Pioneer and the Mariner sensor, the configurations of which significantly differ in many respects. To obtain comparative data after completing the Pioneer type magnetometer tests, a Mariner 5 sensor was reassembled and put into operation. The variations in Mariner offset with temperature, rf power, temperature gradient, etc., were determined. As with the Pioneer sensor, thermo-electric currents in the Mariner sensor housing proved to be one of the largest contributors to offset changes.

A series of comparative tests were carried out between the advanced version of the vector helium magnetometer (VHM) and a new version of the Ames Research Center (ARC) fluxgate magnetometer. The tests were performed at JPL using the cryogenic flux tank and the magnetically shielded room. The tests demonstrated the superior sensitivity and stability of the VHM. They served as the basis of a joint proposal for the Mariner/Jupiter/Saturn (MJS) mission which called for the use of the VHM to measure weak interplanetary fields and planetary fields up to 1Γ and the use of the ARC fluxgate magnetometer for the measurement of planetary fields up to 10Γ.

A proposal was also submitted to use the Pioneer VHM on the Heliocentric Orbiter portion of the International Magnetospheric Explorer (IME) mission. The proposal was accepted and a VHM experiment is now planned for the heliocentric spacecraft.

~~D-13~~
D-18

THEORETICAL SPACE PLASMA PHYSICS

NASA Work Unit 188-36-55-02-55
JPL 603-35310-0-8280
T. W. Unti

OBJECTIVE

The objective of this work is to conduct theoretical space physics research to help interpret and suggest NASA Fields and Particles experiments.

PROGRESS

The Shock Ensemble of February 2, 1969

A variety of discontinuities may be generated by a solar flare of sufficient energy. These discontinuities, which propagate through or are convected in the solar wind, may be recorded by spacecraft field and plasma instruments. The pattern which characterizes a flare induced shock system consists of a forward fast shock, a tangential discontinuity which announces the onset of a helium-rich piston, and a reverse fast shock. Other discontinuities may be (and usually are) present, but they are not as important conceptually. Several theoretical models have been proposed for flare induced shock pairs, and for the related shock system generated by an M-region beam, the movement of a fast into a slower stream.

The event observed by both Pioneer 9 and OGO 5 on 2 Feb 69 consisted of the following major discontinuities: (1) a forward slow shock, (2) a forward fast shock, (3) a tangential discontinuity at which the density dropped sharply and the flow direction changed, (4) a tangential

discontinuity at which the magnetic field strength jumped to an unusually high value, (5) two closely spaced tangential discontinuities which bracketed a region of even greater field strength and which fronted a region of very cool, very dense, helium enriched plasma, (6) a reverse fast shock of low Mach number, and (7) a second reverse fast shock of very low Mach number. Perhaps the most curious aspect of the 2 Feb 69 event is that it exhibited some properties which are usually attributed exclusively to flare induced events and other properties strongly indicative of corotating systems. The event occurred at the leading edge of a new sector, which was observed about 27 days before and about 27 days after the 2 Feb 29 shock system. This suggests the event was a corotating structure. There were several other indications of corotation: for example, the existence of 2 reverse shocks, the spiral alignment of the tangential discontinuity which fronted the helium piston, the non-deceleration of the piston between Pioneer and OGO, and the lack of a plausable flare association (although flare associations are often ambiguous). On the other hand, the shocks themselves were not observed one solar rotation before and after 2 Feb 69, the normals to the reverse shocks were pointed back toward the sun, low temperatures behind the piston indicated the presence of a magnetic bottle, and most significantly, a helium piston was present between the forward and reverse shocks.

These seemingly contradictory pieces of evidence were resolved by the suggestion that the 2 Feb 69 event was generated by a flare errupting at the site of an M-region. This agrees with the observation that solar flares tend to occur in active regions, and thus might occur preferentially

near the sources of high speed streams. It is also consistent with the "sputtering M-region" observed and analyzed by Croft in 1972 using radio scintillation techniques.

Spectral Analysis of OGO 5 Data

The controversy concerning the distribution of inhomogeneities in the solar wind has not yet been resolved. Several workers in the field of radio scintillation have claimed the existence of small scale density irregularities in the solar wind; their claim has been disputed by those who predict a continuous distribution of irregularities, from the largest to the smallest scale sizes.

A spectral analysis of the OGO 5 flux data was performed. In about one-third of the cases studied, power enhancements were evident between 0.1 and 1.0 Hz, which is precisely the frequency range at which small density enhancements, or "blobs" being convected in the solar wind, would occur. After publication of these results, a second analysis was initiated to determine if the spectral enhancements were statistically significant.

A variety of tests seemed to indicate that the spectral flattening does correspond to a real solar wind phenomenon, whether it be waves, discontinuities, blobs, or some other effect. Spectral analysis of magnetic field data then revealed a very interesting and unexpected result: where enhancements were present in the flux spectra, enhancements were also usually present in the corresponding field spectra, often with surprising strength and clarity. Yet cross-spectral analyses between field and plasma rarely showed any significant coherence! Two

interpretations suggest themselves: (1) the blobs exist contiguously in a fraction of the data record, so that cross-spectral analysis over the entire record could statistically "wash out" any coherence that might exist; (2) the density blobs and field enhancements are real, but are uncorrelated, although this alternative may prove difficult to explain theoretically. Further analysis is in progress.

PUBLICATIONS

External Publications

T. Unti, M. Neugebauer, B. E. Goldstein, "Direct Measurements of Solar Wind Fluctuations Between 0.0048 and 13.3 Hz.", Ap. J. 180, 591 (1972).

T. Unti, M. Neugebauer, C. S. Wu, "The Shock System of February 2, 1969," accepted for publication in Jour. Geophys. Res.

Meeting and Symposia Papers

T. Unti, M. Neugebauer, "Major Discontinuities Between an Interplanetary Shock Pair," presented at the Conference on Flare-Produced Shock Waves in the Corona and Interplanetary Space, Sponsored by the High Altitude Observatory, Boulder, CO, Sept. 11-14, 1972.

T. Unti, M. Neugebauer, "The Helium Piston of 2 Feb 69," AGU annual Fall meeting, San Francisco, Dec. 4-7, 1972.

T. Unti, C. T. Russell, C. S. Wu, M. Neugebauer, "A Study of Features Between 0.1 and 1.0 Hz in Solar Wind Ion Flux Power," AGU annual Spring meeting, Washington, D. C., Apr. 16-20, 1973.

Interstellar Microwave Spectroscopy/Engineering Support

NASA Code: 188-41-52-04-55

JPL Code: 603-45210-0-3330

Sato, T.

Objective

The objective of this work is to provide engineering support to the Interstellar Microwave Spectroscopy/Observations Task. Included are the maintenance, upgrade, and operation of those key subsystems required for the observations.

Progress

Continued the observations of the $2_{12} - 2_{11}$ transition of formaldehyde and mapping program. Also, observations were conducted to search for heavy element recombination lines.

Engineering support to the observing program over the past year has provided valuable experience and insight towards defining areas of improvement to increase the observational efficiency.

Since the start of observations, a new X-band traveling wave maser (TWM) has been incorporated into the system which can be remotely tuned over its entire operating range (7.75 - 8.75 GHz).

Both the X and K-band local oscillator systems are gradually being changed over to solid state systems with progress being made to also remotely tune them.

Plans

1. Continue work to allow K-band TWM to be remotely tuned.
2. Continue work to remotely tune X and K-band local oscillators.
3. Upgrade autocorrelator with regard to bandwidth and channels.
4. Improve the video converter bandwidth and operation.

Publications

Evans, N.J., G. Morris, T. Sato, B. Zuckerman, "Formaldehyde in Dark Nebula: Absorption of the Isotropic Background Radiation at 2 cm Wavelength", Bulletin, Am. Astron. Soc., 4, 3, Part 1, 1972, p. 307.

~~GRFT~~
D-20

INTERSTELLAR MICROWAVE SPECTROSCOPY/LAB. PROGRAM

NASA Work Unit 188-41-52-05-55

JPL 603-45220-0-8250

R. Poynter

OBJECTIVE

The objective of this task is to conduct a laboratory microwave spectroscopy program aimed at providing both experimental data and theoretical interpretations of microwave absorption and emission lines which occur in the interstellar medium. The laboratory spectrometer used in the pursuit of these objectives was funded from a JPL Director's Discretionary Fund grant. Support of the system operation, data taking, analysis and interpretation, is funded by this task.

PROGRESS

Laboratory Instrumentation

The laboratory instrumentation consists of a commercially available Stark effect modulation microwave spectrometer (manufactured by Hewlett-Packard), and an automatic data acquisition and control system. The basic spectrometer, which covers the frequency range between 8 GHz and 40.0 GHz in four bands, was delivered, installed and checked out by August 1972. The spectrometer is a low Stark modulation frequency type instrument with a 6 ft. absorption cell. The minimum detectable absorption coefficient is 10^{-9} cm^{-1} in the operating temperature range between -80°C and +80°C. The operating pressure range is 0.01 to 200 millitorr. The spectrometer control system was delivered in September 1972. Checkout was completed in October. A design flaw in the control system was detected in November '72, and corrected in January '73.

The pressure measuring system was delivered in October '72. Tests showed that the pressure measuring gauge was inoperative upon delivery. It was returned to the factory for warranty repairs. The completed system became operational during the first part of December '72.

Special frequency sweep control programs have been written and tested on NH_3 and H_2CO. Linewidth measuring control programs have been written and are being tested.

Laboratory Measurements

All of the ground state NH_3 transitions from 8 GHz to 40 GHz have been measured. All K band (18 - 26.5 GHz) linewidths have been measured and collision cross sections have been determined. The absorption coefficients have not yet been measured. All of the v = 0001 lines between 8 GHz and 53 GHz have been measured for both $^{14}NH_3$ and $^{15}NH_3$. Both sets of lines have been assigned and spectral constants have been determined. An analysis of these spectra is being published.

Linewidths and collision cross sections are being measured for H_2CO. Measurements of the corresponding absorption coefficients will be done during FY'74.

A scan of the CH_3CHO spectrum has been made. Several problems are apparent from a preliminary spectral analysis. Some earlier work on the OH and OD free radicals is being written up for publication.

PUBLICATIONS

Meeting and Symposia Papers

1. E. A. Cohen and R. L. Poynter "The Inversion Spectrum of $^{14}NH_3$ in the $000^0 1^1$ Vibrational State," Symposium on Molecular Structure and Spectroscopy, Ohio State Univ., 1972.

2. E. A. Cohen and R. L. Poynter "The Inversion Spectra of $^{14}NH_3$ and $^{15}NH_3$ in the $000^0 1^1$ Vibrational State," Bull. Am. Phys. Soc. 18, 407 (1973).

PULSAR ROTATION CONSTANCY

NASA Code: 188-41-52-09-00
JPL Code: 603-45230-0-3310

P. E. Reichley

OBJECTIVE

The objectives of this work unit are summarized as follows:

1. Monitor the behavior of the erratic Vela pulsar on a weekly basis.
2. Measure the second-order changes in pulse period for a clue to the radiation mechanism.
3. Measure the proper motion of pulsars to determine if they are extra-high velocity stars.

PROGRESS

All existing data on twenty-three pulsars was added to obtain a pulse shape template for each pulsar. The templates were correlated with the data to obtain optimal estimates of the times-of-arrival.

A computer program was constructed that will analyze the data in a least squares sense. The program takes the data and the latest JPL ephemeris and solves for various parameters.

Data was taken on the 64m antenna at 2.4, 8.4 and 15.1 GHz. An analysis was made of the energy and the pulse shape as a function of frequency. Simultaneous observations at 2.4 and 8.4 GHz were made on the 64m antenna.

Time-of-arrival data was collected on both the 26m and 64m antennas throughout the year. The data was collected at intervals of no less than one week.

PLANS

1. All existing data on the twenty-three pulsars will be analyzed using the least squares program. A special study will be done for the Vela pulsar because of its erratic behavior.
2. Simultaneous observations at 2.4 and 8.4 GHz will be made to determine if the integrated electron density between the Vela pulsar and Earth is constant.
3. Data will continue to be collected at intervals of no less than one week.

PUBLICATIONS

1. "Vela Timing Observations", P. E. Reichley and G. S. Downs, Annals of New York Academy of Sciences, (in press). (Paper given at Sixth Texas Symposium on Relativistic Astrophysics, 20 Dec. 1972, New York, N.Y.).
2. "Pulsar Detections at Frequencies of 8.4 and 15.1 GHz", G. S. Downs, P. E. Reichley and G. A. Morris, Ap. J., Vol. 181, pp. L143-L146 (May 1, 1973).
3. "Simultaneous Detection of Pulsar Radiation at S and X Bands", P. E. Reichley, G. S. Downs, G. A. Morris and D. A. Bathker, The DSN Progress Report, Technical Report 32-1526, Vol. 15, pp. 133-137, JPL, Pasadena, Calif., June 15, 1973.

~~OMIT~~
D-22

INTERSTELLAR MICROWAVE SPECTROSCOPY/OBSERVATION SUPPORT

NASA Work Unit 188-41-52-12-55

JPL 603-45232-0-8250

S. Gulkis

OBJECTIVE

An astronomical observing program aimed at studying microwave transitions of interstellar molecules came into full operation during 1972-73. Astronomers from the University of California at Berkeley, the University of Maryland, and JPL participated in the program. NASA's Deep Space 64-m antenna at Goldstone, Calif. was used at S-band (2 GHz), X-band (8 GHz) and K-band (15 GHz). Observations during 1972 were primarily of the $2_{12} - 2_{11}$ transition of interstellar formaldehyde (H_2CO; rest frequency: 14.4886 GHz).

PROGRESS

This program's primary accomplishments were as follows:

1) The first observations have been made of the 2 cm line of formaldehyde in "anomalous" absorption against the isotropic background (3°K) radiation. This enables one to distinguish among the various models that have been suggested to cool the 6 cm transition of H_2CO and also to set severe constraints on the properties of the isotropic background at 2mm wavelength.

2) In Orion A, the first observations have been made for any H_2CO K-doublet transitions in emission (as opposed to absorption). This indicates that high densities are present so that collisions quench the otherwise ubiquitous cooling of H_2CO. The 2 cm emission line was mapped to learn the extent of the dense central portions of the Orion molecular cloud for comparison with the large body of other data that exists for this H II region.

3) The first high resolution maps of absorption lines have been obtained with a single antenna. Comparison with emission line maps of similar resolution obtained at mm wavelengths will enable us to better distinguish gases located in front of and behind continuum sources.

In addition to the formaldehyde work, the hydrogen recombination line (H92α) was measured in the direction of the supernova remnant 3C 391. An

unsuccessful search for a recombination line of deuterium (D92α) places a limit on the deuterium abundance of $[D]/[H] < 1.6 \times 10^{-3}$. The result supports the suggestion that chemical fractionation may be responsible for the enhanced DCN emission from Orion.

A negative search was made for the molecules CH_2NH, H_2O_2, and H_2CS.

In addition to the work described above, current projects include a search for the J = 3/2 and J = 5/2 transitions of the $^2\Pi_{\frac{1}{2}}$ state of OH, as well as the J = 5/2 transition of the $^2\Pi_{\frac{1}{2}}$ state of OD.

PUBLICATIONS

External Publications

1. D. A. Cesarsky and C. J. Cesarsky, "High Frequency Observations and Theoretical Interpretations of Recombination Line Emission in the Direction of Supernova Remnant 3C 391," Astrophysical Journal, (in press).

2. D. A. Cesarsky, "Deuterium Recombination Line Emission," Astrophysical Journal (in press).

Meeting and Symposia Papers

1. N. Evans, G. Morris, T. Sato, and B. Zuckerman, "Formaldehyde in Dark Nebulae: Absorption of the Isotropic Background Radiation at 2 cm. Wavelength," Am. Astron. Soc., Michigan Meeting, 1972.

~~DRAFT~~
D-23

JPL Support of ESRO Studies
NASA Work Unit 188-41-54-04-55
JPL 603-45440-0-1310

R. W. Davies

The European Space Research Organization (ESRO) has been conducting studies to determine the feasibility of making very accurate tests of the General Theory of Relativity with a specially designed spacecraft placed in solar orbit. The experimental goals would be a measurement of the General Relativistic time delay to approximately one part in 10^4 and to separate the effects of solar oblateness and General Relativistic effects on the motion of a satellite of the sun.

The JPL has been assisting NASA in making joint evaluations with ESRO of their study. The JPL role has been primarily in making error analyses, assisting in making comparisons with other missions, and providing information of the future of radio ranging with spacecraft.

JPL error analysis have been consistent with the results obtained by ESRO using an entirely different mathematical program. If successful the ESRO mission (called SOREL) would provide the most accurate tests of the General Theory of Relativity yet envisioned.

A first phase of a final report was received by ESRO recently. This report is being evaluated. The year end NASA-ESRO review was delayed.

Anticipated Meeting: Year end NASA-ESRO review.

Anticipated Reports: Suggestions for modifications of the SOREL.

~~D-24~~
D-24

HIGH RESOLUTION IR STELLAR SPECTROSCOPY

NASA Work Unit 188-41-55-08-55

JPL 603-45510-0-8250

Reinhard Beer

OBJECTIVE

The objective of this task is to acquire and analyze high resolution stellar spectra at near infrared (1-6 microns) wavelengths. The principal instrumentation employed is a Connes'-type Fourier spectrometer operated at the coude' focus of the 107" telescope, McDonald Observatory. The program is undertaken with the active collaboration of the Astronomy Department of the University of Texas at Austin, the primary aim being to aid in the understanding of the composition, structure and evolutionary state of late-type stars and variables. A secondary objective is to provide back-up data and operational experience in order to participate fully in future LST and Shuttle Observatory missions.

PROGRESS

The Connes'-type Fourier spectrometer used in this program is primarily dedicated to a program of planetary infrared spectroscopy and, during planetary observing runs, stellar spectra can only be taken when no actual planetary observations are being made. Consequently, it is necessary to obtain stellar spectra in the general wavelength region demanded by the planetary program. There are two such regions: 1.4 to 2.7 microns and 2.9 to 5.8 microns. At the present time, we are operating in the short-wavelength region. On the other hand, there are many more stars observable in this region and, furthermore, the University of Texas personnel are now sufficiently experienced in the use of the system to undertake some of the observing without our physical presence. We still, however, undertake all instrument maintenance and improvements (some of which will be discussed later) and all raw data reduction. We hope to transfer some of this latter operation to Texas early in the year.

Observing Program

During the past years, we have observed the following objects:

Object	Type	# of Spectra	Resolution (cm^{-1})	Comments
α Her	M5 II	8	0.15	
α Boo	K2 III p	10	0.10	
α Sco	M1 I b	5	0.15	
β Peg	M2 II-III	12	0.20	
O Cet	M4-7 III e	16	0.15	Various phases inc. minimum
R Lyr	M5 III	3	0.20	
R Leo	M8 II e	13	0.10	Various phases after maximum
U Hya	C7	5	0.30	
X Cyg	S7 e	5	0.15	
W Hya	?	3	0.20	
R Hya	M7 II e	3	0.15	

The massive task of transforming and reducing these spectra is in hand.

An interesting adjunct to the observing program has been undertaken by T. A. Barnes who has, using the Warner & Nather High Speed Photometer, observed flashes in the output of the faint white dwarf companion to Mira (O Cet) which are interpreted as matter falling into the white dwarf from the atmosphere/dust surrounding Mira. Analysis of these data together with our spectra may enable us to make much stronger assertions concerning the shell around Mira.

Analyses

D. Lambert and R. Beer have published a tentative identification of the NH radical in α Ori. This radical is most important because it avoids the well-known difficulties of analyzing the CN electronic bands and may, ultimately, permit us to make direct nitrogen abundance determinations, a massive "missing link" in the CNO cycle.

Analyses in hand are concerned with the identification of the S2 and S3 lines of the 2-0 quadrupole H_2 band in cool stars. It is felt that the identifi-

cation is probably incorrect. Other work pertains to the identification of $^{29}Si^{16}O$ and the $^{28}Si/^{29}Si$ isotope ratio in our spectra and $^{12}C/^{13}C$ isotope ratios from scanner data as compared to our own.

R. Beer, D. Lambert and T. G. Barnes have reported on the 0.1 cm^{-1} observations of α Ori made in 1971 and early 1972. R. Beer has submitted a paper to J. Mol. Spec. analyzing the $\Delta V = 2$ SiO bands in these spectra from a physical standpoint and deriving new, improved, molecular constants for this important radical. R. Beer has also produced new energy levels for the ground-state of the OH radical, employing the frequencies of the $\Delta V = 1$ and $\Delta V = 2$ sequences seen in our stellar spectra and the $\Delta V = 2$ sequences seen in sunspot spectra (D. Hall, KPNO). An empirical modification of Mizushima's theory for the OH energy levels was discussed at the Indiana Cool Star Conference in 1972 based upon these data. The empirical theory was later improved and succeeded in matching all known energy levels (some 400 values) with an RMS error of 0.05 cm^{-1}. This represents an improvement of more than 2 orders of magnitude over Mizushima's theory, which is certainly the best quantum mechanical treatment available to date. M. Geller of JPL is currently engaged in a new quantum mechanical analysis of OH and publication of the data will follow shortly.

Instrumentation

Although not supported by this task, some instrumental parameters are worth noting.

(1) The automatic image stabilizer/guider, which was not expected to operate on objects having $M_V > 7.5$, successfully operated on Mira at minimum light ($M_V \sim 8.8$). This was most gratifying.

(2) The rolling-ball carriage for the interferometer is being replaced by a linear air-bearing and a new linear motor. The effects of this will be to

(a) reduce the effects of vibration because of lower friction

(b) increase the bandwidth of the step-and-lock servo, thereby reducing the settling time

(c) double the available resolving power. The minimum resolution will now be 0.02 cm^{-1} (apodized)

Installation of this modification is expected about November-December 1973.

(3) System control is to be undertaken by a PDP8E computer. The computer will

(a) Perform data re-formatting and housekeeping, reducing the workload and the cost of the reduction routines.

(b) Sense the moving carriage velocity, making it less sensitive to dirt on the ways.

(c) Guide the telescope.

The result of these changes, which are in hand at the present time, will be

(a) to reduce the number of observers needed by a factor of 2.

(b) increase observing efficiency (time actually spent integrating starlight/total time at the telescope) by at least 40%.

Future Plans

Future plans for the remainder of the current year call for continuing observation of R Leo to follow it through its cycle (~ 300 days) and further observations of α Boo, α Sco, α Her and Mira in order to improve our statistics, which are presently insufficient on these objects.

It is also our plan to keep abreast of, and as far as possible involved in, planning for the Shuttle Sortie Mode. It is our feeling that this operating mode offers the greatest possibilities for useful infrared stellar and planetary spectroscopy at high resolution, because of the complexity of the equipment involved.

PUBLICATIONS

External Publications

1. Beer, R., Norton, R. H., Hutchison, R. B., Lambert, D. L. and Martonchik, J. V. "Observation of the OH Radical in Betelgeuse", Mem. Roy. Soc. Liège 3 (6th series), 145 (1972).

2. Lambert, D. L. and R. Beer "Vibration-Rotation Bands of NH in the Spectrum of Alpha Orionis," Ap. J. 177, 514 (1972).

3. Beer, R., Barnes, T. G and Lambert, D. L. "Improved Parameters for the $^{28}Si^{16}O$ and $^{16}O^{1}H$ Molecules," Proceedings of the Indiana Cool Star Conference (in press).

D-25

ORIGIN AND EVOLUTION OF ASTEROIDS AND SMALL BODIES

NASA RTOP 188-45-51
JPL 603-65101-0-3910

J. G. Williams

OBJECTIVES

The objectives for the FY'73 study were to find and study the fragment clusters from asteroid collisions which are called families, to derive the so-called proper elements which are needed to find families for newly cataloged asteroids, to investigate the orbital evolution of special objects by numerical integration, and to investigate fireball orbits using the means which have proved very successful for asteroids.

PROGRESS

Asteroid Families and Proper Elements

An asteroid family is a cluster of asteroid orbits which show that the family originated in the breakup of a parent asteroid. These breakups are thought to have resulted from violent collisions. By investigating these families we are able to learn about the evolution of the asteroid belt since it formation.

The first step in this investigation of asteroid families was the calculation of proper elements. Proper elements are orbital elements which have had the effects of planetary perturbations subtracted out. Proper elements were calculated for the few asteroids which had not been done prior to this contract. This gave a set of 3566 objects of which 2822 had accurate enough orbital elements to be used in searches for families.

Families are found by looking for clusterings of the three proper

elements; a, semimajor axis, e, eccentricity, and i, the inclination. This search has been done visually by making computer plots of stereo pairs of small volumes of a-e-sin i space, where each asteroid is represented by a point in the space. When plots are examined with a stereoscope the families show up as three dimensional groupings. I find this method superior to using two dimensional projections as clustering in the third dimension is immediately apparent.

The search for families started at the outer boundary of the belt (4 au) and has been progressing inward. It has been completed in to 2.5 au. About 2/3 of the total number of objects have been searched. At the present time about 70 families have been found which satisfy the criterion that the Poisson probability of the occurence of the clustering by chance is no more than 1/3000. An almost equal number of families have been found which do not meet this strict criterion. Of these most are thought to be real and the majority of these small families will pass the significance test with the addition of one more new family member. This searching for families has gone slower than anticipated due to the very large number which have been found. In the densest regions families are quite crowded. The searching of the last third of the belt for families will have to be completed in FY'74.

For each of the families found so far a number of properties have been calculated and tabulated. The location in a, e, and sin i and the number of members are recorded. The individual members and their properties are listed. The size and shape of the family is expressed in terms of the standard deviations and correlations of the distributions in a, e, and sin i.

~~GSFC~~
D-26

X-RAY AND GAMMA-RAY ASTRONOMY

NASA Work Unit 188-46-53-01-55
JPL 603-55310-0-8280
603-55311-0-8230

A. S. Jacobson

OBJECTIVE

The objective of this program is to detect X-ray and gamma-ray line emissions from celestial sources. The observation of such sources would provide important information on nucleosynthesis, galactic history, and the nature of cosmic X-ray sources. To accomplish this objective, high spectral resolution spectrometers are being developed and adapted to balloon and space flight systems.

PROGRESS

Analysis of the observation of Scorpius XR-1 was completed. This observation was made with our 5 cc solid state detector system. No lines from this source were observed and upper limits of about 3×10^{-3} photons/cm^2-sec were established from 20 to 150 keV.

The prime activity in FY'73 was the development of a new and greatly advanced balloon-borne solid state detector system. This system, centered around a cluster of four Ge(Li) crystals with a combined active volume of 160 cc, will provide an order of magnitude increase in sensitivity over the previously used high resolution spectrometer. It represents a major capability for low energy gamma-ray astronomy.

During FY'73, a complete electronic data and power system was designed and fabricated, and testing is now in progress. This system includes four 8192 channel pulse height analyzers with associated pulse shaping amplifiers. This has been a highly successful effort and a line width of 2.3 keV at 1.332 MeV has been achieved. This is as good as our laboratory system.

Additional subsystems are a digital multiplexer and encoder, housekeeping ADC, command router and all necessary power supplies. Ground station requirements were identified and all necessary equipment assembled.

The sensor constituents have all been procured and assembly is nearing completion. The four piece CsI anticoincidence shield is complete except for the collimator. The housing for this has been fabricated and assembly will take place soon. A cradle was built to provide mechanical support for the sensor and the dewar required to provide cooling for the Ge(Li) crystals.

During the year, several operations were performed with the Ge(Li) crystals and their vacuum cryostat. These included opening the cryostat and baring the crystals, something we had never done before. The operation improved the functioning of the detectors and contributed significantly to our understanding and confidence in applying them to balloon and space-borne experiments.

The balloon flight gondola was designed, constructed and integration begun. The design allows us to retrofit servo systems and perform test and observation flights with the same apparatus. An engineering, test and sensor study flight of this new system is scheduled for January, 1974.

PUBLICATIONS

External Publications

A. S. Jacobson, "Cooled X-Ray and Gamma-Ray Detectors for Space", Proceedings of the Cryogenic Workshop, MSFC, 65(1972).

~~D-15~~
D-27

GEOLOGY AND MINERALOGY

NASA Work Unit 195-42-55-01-55

JPL 605-25501-0-8260

J. E. Conel and R. J. Phillips

OBJECTIVE

The Geology and Mineralogy task is a coordinated program of experimental and theoretical research directed at understanding the surface and subsurface properties of the moon, the nature of processes that have produced and modified the surface and subsurface, and determination of the evolutionary history of the moon by analysis of available geophysical and geochemical information. Where necessary, new analytical techniques are developed to achieve this goal. The ultimate objective is to use our knowledge of the history of the moon to understand histories of the terrestrial planets.

PROGRESS

Inversion of Geophysical Data (Lunar Gravity Studies)

Continuing studies of gravity anomalies over circular lunar basins, aided by profile data from the Lunar Sounder experiment, have led to a working hypothesis for basin evolution following impact formation. The circular basins underwent isostatic adjustment by mantle rebound and volcanic flooding. Subsequent superisostatic flooding gave rise to large free-air gravity anomalies. The ensuing partial isostatic adjustment explains many of the observed surface features of these basins. This work was reported at the May COSPAR meeting in Germany.

The specific techniques utilized for inversion of lunar gravity data have been discussed in a paper submitted to the Journal of Geophysical

Research. The ultimate technique for inverting Doppler gravity involves a simultaneous estimation of the Keplerian elements of spacecraft motion and the generalized elements of a geophysical model. The computer program to carry out this technique is now operational.

Lunar Thermal History and Heat Flow

Study of lunar thermal models and various constraints supplied by analysis of lunar samples, and geochemical and geophysical information, has continued. Following update and submission of our final report on INTERPRETATION OF APOLLO RESULTS (Physical Constraints on Lunar Thermal History: An Analysis of Results from Investigation of Lunar Samples and Geophysical Data by J. E. Conel, F. P. Fanale, and R. J. Phillips, July, 1972), efforts were concentrated on two specific problems: (1) analysis of the Apollo 15 and 17 heat flow results, and (2) thermoelastic deformation of the moon. Only (1) will be treated here. (2) is the subject of a continuing investigation which will involve coupling the thermoelastic with tidal deformation. The present stress state of the interior requires, among other things, specification of the temperature distribution, as this is obtained in our formulation, from the thermal history. The ultimate goal here is to understand the origin, location, and significance of indigeneous lunar seismic activity.

Lunar surface heat flux is an important boundary condition on thermal models. If steady conditions are assumed between flow and production, then the present heat escaping gives directly an indication of heat-producing radionuclide abundances in the interior. The heat flow experiments on Apollo 15 and 17 gave values of the surface flux some five to seven times that expected from previous theoretical work and from microwave

observations of the flow. The in situ numbers obtained imply enormous concentration of U in the interior, and if the radioactivity were uniformly dispersed, central lunar temperatures of nearly 1.2×10^4 °K! To some investigators these numbers imply large local abundances of radioactivity. Our previous exploratory work with lunar thermal models strongly suggested, however, that a major clue to the early chronology of lunar igneous events was the high thermally insulating nature of the lunar regolith, which by various arguments must be thicker in highland than in mare regions. Both sites of heat flow measurement on the moon are transition regions between provinces of thin and thick surface insulation. We sought to investigate effects of such discontinuities in the boundary layer on measured values of the flux. An analytic solution to the appropriate inhomogeneous Fourier problem of the second kind was found, but numerical evaluation of integrals appearing in the solution proved to be excessively time-consuming. It was decided to attack the problem directly by finite difference methods. The solutions have been obtained, and with them we are investigating time-dependent problems of surface heat flow with internal heat generation and initial heat, and with laterally varying surface insulation. As a numerical example of the results, for a geometry appropriate to the Apollo 15 site, with 10 m of mare regolith and 1 km of highland regolith, an anomalous heat flow 15 times the nominal value occurs at the discontinuity. Thus, the Apollo 15 and 17 heat flow results could represent equilibrium flow from a lunar crust 50 km thick containing chondritic abundances of U, with initial heat contribution arising from cooling from the (basalt) melting point gradient. No abnormal concentrations of radioactivity are required. The results suggest the crucial importance

of geologic setting in interpretation of such geophysical data. On our model, the Apollo 16 heat flow measurement would have been crucial in providing a more nominal global value for the surface flux. These results are presently being prepared for publication.

Multispectral Telescopic Observations and Laboratory Reflectance Studies

A new silicon imaging photometer (SIP) has been developed, and preliminary tests at the Mt. Wilson 60-inch telescope have been made. The exceedingly severe TVI problems inherent at this site have largely been overcome! Work has begun on photometric calibration of the system. The telescope program will provide relative spectrophotometric information in the spectral region 0.4 - 1.1 μm in pictorial (digital) format, and with dynamic range on the order of 10^3. These data will eventually be correlated with Apollo orbital photography and orbital data from the gamma-ray, x-ray, infrared, and ALSE experiments.

The observations will further be supported by laboratory studies of reflectance properties of actual lunar material and simulation mixtures. A study has been completed on vacuum vitrification of rocks. Our experiments show that albedos as low as those on the moon can be produced by vitrification and associated chemical fractionation of ordinary terrestrial basaltic material. The spectral reflectance properties of glass powders are significantly different from those of the parent rock. The presence of ubiquitous glass in lunar surface material complicates compositional determinations using spectral reflectance methods. Vitrification of rocks on the moon may result in chemical fractionation, such that glass fragments found in the soil may not be representative of the chemistry of bulk parent rock (or glassy) material. We have been led to coin the term "ultimate glass" to describe a refractory-rich opaque

material (at this point hypothetical) that is the result of repeated vapor fractionation of volatile constituents through impact. A study of the reflectance systematics of mineral mixtures (hypersthene, labradorite, and ilmenite) has been completed and is being prepared for publication.

PUBLICATIONS

External Publications, Meeting and Symposia Papers

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Phillips, R. J., J. E. Conel, and W. I. Sjogren, "The Nature of Circular Maria Based on Gravity Studies", (in press), Proceedings of the XVIth Meeting of COSPAR, 1973.

Phillips, R. J., "Techniques in Doppler Gravity Inversion", paper given at Symposium on Inversion of Geophysical Data, University of Utah, 1973, and submitted to Journal of Geophysical Research, 1973.

Internal Publications

Conel, J. E., F. P. Fanale, and R. J. Phillips, "Physical Constraints on Lunar Thermal History: An Analysis of Results from Investigation of Lunar Samples and Geophysical Data", JPL Technical Document 900-522, 102 pp., 28 July 1972 (Revised).

D-28

GAMMA RAY SPECTROSCOPY

NASA Work Unit 195-42-55-01-55
JPL 605-25503-0-8280
A. E. Metzger

OBJECTIVE

The objective of this program is to investigate the capability of gamma ray spectroscopy for lunar and planetary applications, and to develop the techniques of data analysis and interpretation. Specifically, the emission of induced gamma ray fluxes is to be studied by high energy accelerator bombardments as a means of evaluating the comparative response capability of scintillation and solid state detector systems and to aid in the interpretation of gamma ray spectroscopy data from Apollo 15 and 16.

PROGRESS

As part of the effort to translate Apollo 15 and 16 data into lunar chemical compositions, a series of irradiations were made at the Lawrence Berkeley Laboratory's Bevatron last fall. These included the use of several thick targets to simulate the interaction of cosmic rays with the lunar surface, boron shielding for the reduction of background and the use of a cooled germanium solid state detector in addition to a NaI crystal to provide better peak resolution of the induced activities. The data is presently being reduced.

A new type of solid state detector, made of high purity germanium, has attracted our attention because of its ability to survive at ambient temperatures on the ground and in space. ARPA has begun to support a substantial developmental program for a non-space application; the program is being directed by the NRL. Conversations have been held with supplier and user groups around the country

regarding the status and future development of this device. A first look at the simplest way of handling thermal control for sufficient cooling during operational periods indicates that a passive thermal control design would be possible.

PUBLICATIONS

External Publications

James Arnold, A. E. Metzger, Laurence E. Peterson, Robert C. Reedy, J. I. Trombka, "Gamma Ray Spectrometer Experiment", Apollo 16 Preliminary Science Report (NASA-SP-315)

James Arnold, A. E. Metzger, L. E. Peterson, R. C. Reedy, J. I. Trombka, "Lunar Surface Radioactivity: Preliminary Results of the Apollo 15 and 16 Gamma Ray Spectrometer Experiments", Science Vol. 179, pp 800-803, 1973

A. E. Metzger, J. I. Trombka, L. E. Peterson, R. C. Reedy, J. R. Arnold, "A First Look at the Lunar Orbital Gamma Ray Data", Proceedings of the Third Lunar Science Conference, MIT Press, Vol. 3, Frontespiece, 1972.

A. E. Metzger, R. C. Reedy, L. E. Peterson, J. I. Trombka, J. R. Arnold, "Lunar Orbital Gamma Ray Measurements from Apollo 15 and Apollo 16", Space Research XIII (COSPAR) Akademie - Verlag, Berline 1973

A. E. Metzger, I. Adler, J. I. Trombka, P. Lowman, R. Schmadebeck, H. Blodget, E. Eller, L. Yin, R. Lamothe, G. Osswald, J. Gerard, P. Gorenstein, P. Bjorkholm, H. Gursky, B. Harris, J. Arnold, R. Reedy, "Apollo 15 and 16 Results of the Integrated Geochemical Experiment" , THE MOON, to be published.

Meeting and Symposia Papers

A. E. Metzger, R. C. Reedy, J. I. Trombka, L. E. Peterson, J. R. Arnold, "Apollo 15 and 16 Gamma Ray Results", abstract, Proceedings of the Geophysical and Geochemical Conference, January 10-12, 1973

J. I. Trombka, J. R. Arnold, R. C. Reedy, L. E. Peterson, A. E. Metzger, "Some Correlations Between Measurements by the Apollo Gamma-Ray Spectrometer and Other Lunar Observations", Lunar Science Institute, Houston, Texas, March 5-8, 1973

D-29

MICROWAVE SURFACE PROPERTIES

NASA Work Unit 195-42-55-07-55

JPL 605-25504-0-8230

W. E. Brown, Jr.

OBJECTIVE

The objective of this task is to study the interaction between radar waves and planetary surfaces, and to be able to determine surface properties (scatterers' size, roughness, dielectric constant....) from the radar echo.

PROGRESS

Our effort in this task was directed toward the understanding of the scattering of active microwaves from lunar surfaces, and the determination of the surface properties (dielectric constant, roughness, scatterer's size...) from the backscattering cross-section.

We conducted studies of the following problems:

1. Backscattering cross-section of a random distribution of half spherical bosses over a flat surface. Our approach was to determine the two dimensional height spectrum of the random bosses, and then use the Rice method to determine the backscattering cross-section.
2. Backscattering cross-section of a random distribution of point scatterers.
3. Preliminary work on the relation between the surface roughness and the "phase jitter" of the leading edge of the return echo.
4. Effect of surface roughness on the design of spaceborne altimeters/profilers.
5. Backscattering from rough subsurface interfaces.

Presently we are studying the mathematical inverse problem where surface properties can be automatically determined from the backscattering function.

The results of this task will be directly applied in our study of the ALSE imagery under the 383 program on "Lunar Data Analysis and Synthesis."

PUBLICATION

D. Evans, "Mathematical Model for the Reflection Coefficients of Dielectric Half Spaces," Radio Science (accepted for publication).

MAGNETIC RESONANCE STUDIES OF GEOLOGICAL SAMPLES

NASA Work Unit 195-42-55-08-55
JPL 605-25509-0-8260

Fun-Dow Tsay* and E. A. Cohen

OBJECTIVE

The objectives of this task are to provide new magnetic resonance data on both terrestrial and non-terrestrial samples and to assess the published results of other workers investigating the magnetic properties of Apollo lunar samples. This will aid us in a more complete understanding of the nature and origin of the ferromagnetic phases (metallic Fe), paramagnetic species and radiation damage centers already observed for the returned lunar samples.

PROGRESS

Our main achievements thus far can be summarized as follows:

1. Detailed spectral comparisons have been made of the electron spin resonance (ESR) signals observed for the lunar samples with those expected for hematite, magnetite, the "unknown ferric oxide" phase of Griscom and Marquardt, the "ferrite" phase similar to $NiFe_2O_4$ of Weeks, and other ferric oxides having the magnetite-like structure. The results of this study have indicated unambiguously that the ESR signals observed for the lunar samples originate from metallic Fe particles and not from ferric ions in paramagnetic or ferromagnetic states.

2. The ESR signals observed for the Apollo 14 and 15 samples as recently reported by other workers are found to be characterized by an asymmetric lineshape with a narrower appearance on the high field side, as was the case for the Apollo 11 and 12 samples. This asymmetry together

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*RRA 1971-72

with the first-order crystalline anisotropy energy ($2K_1/M_s$) obtained from detailed lineshape analyses indicates that these ESR signals again arise from metallic Fe particles having the body-centered cubic structure and not from ferric oxides known to have the face-centered cubic structure.

3. The Apollo 14 samples have been reported by other workers as having the narrower linewidths (600-650G) than those (700-800 G) observed for the Apollo 11, 12 and 15 samples. It is our contention that this difference in linewidth correlates with the Ni and Co contents in these samples. We have demonstrated in our recent work that such a correlation does exist. Now it is possible on the basis of this correlation to estimate the average Ni and Co contents in the metallic Fe phases of the returned lunar samples. From these results, it becomes evident that except for the Apollo 14 fines which are found to have the Ni (8.0 wt %) and Co (0.35 wt %) contents close to those characteristic of meteorites, the bulk of the metallic Fe phases in the returned lunar samples is a direct result of reduction of indigenous Fe^{2+} ions rather than of addition of meteoritic Fe.

4. On the basis of the crystal structure and the crystalline anisotropy energy obtained from our ESR studies, it is concluded that the only metallic Fe particles which can carry a stable natural remanent magnetization (NRM) for longer than 3.0 billion years on the surface of the moon are those with high Co contents and with a diameter at least in the range of 284-384Å.

PUBLICATIONS

1. F. D. Tasy, S. I. Chan and S. L. Manatt, "Electron Paramagnetic Resonance Evidence of Radiation Damage in a Lunar Rock", Nature, 237, 121 (1972).

2. F. D. Tsay, S. L. Manatt and S. I. Chan, "Electron Spin Resonance of Manganous Ions in Frozen Methanol Solution", Chem. Phys. Letters, 17, 223 (1972).

3. F. D. Tsay, S. L. Manatt and S. I. Chan, "Magnetic Phases in Lunar Fines: Metallic Fe or Ferric Oxides?", Geochim. Cosmochim. Acta, 37, 1201 (1973).

ARECIBO DATA REDUCTION

NASA WORK UNIT 195-42-55-10-55

JPL 605-25510-0-8230

T. W. Thompson

OBJECTIVE

Produce a radar map of the moon at 7.5 m wavelength, the longest wavelength used by earth-based observers. This radar map will be produced with the best available resolution using interferometry techniques already developed for previous mappings (Thompson, 1970). Also, radar echo fluctuations will be determined. The mapping and fluctuation determinations will be applied to data obtained in 1970 observations at the Arecibo Observatory.

This work is in support of Geology and Mineralogy RTOP 195-42-55.

PROGRESS

Good progress has been made in the mapping effort. All software has been written and is now being applied to the data. A preliminary map from 40 minutes of data (about one-fifth of the total data) is shown in Figure 1. This map clearly shows that lunar features are resolved with good resolution. Eventually, all of the observations will be folded into a single map and published in a scientific journal.

FUTURE EFFORTS

The study of radar data at meter wavelengths, will continue under NASA programs 383 and 195. The continued study of the existing data will complete the mapping,and studies of signal fluctuations will be done under NASA program 383. New observations and data reduction stressing the polarization characteristics of the echoes will be begun under NASA program 195.

PUBLICATIONS

None

REFERENCES

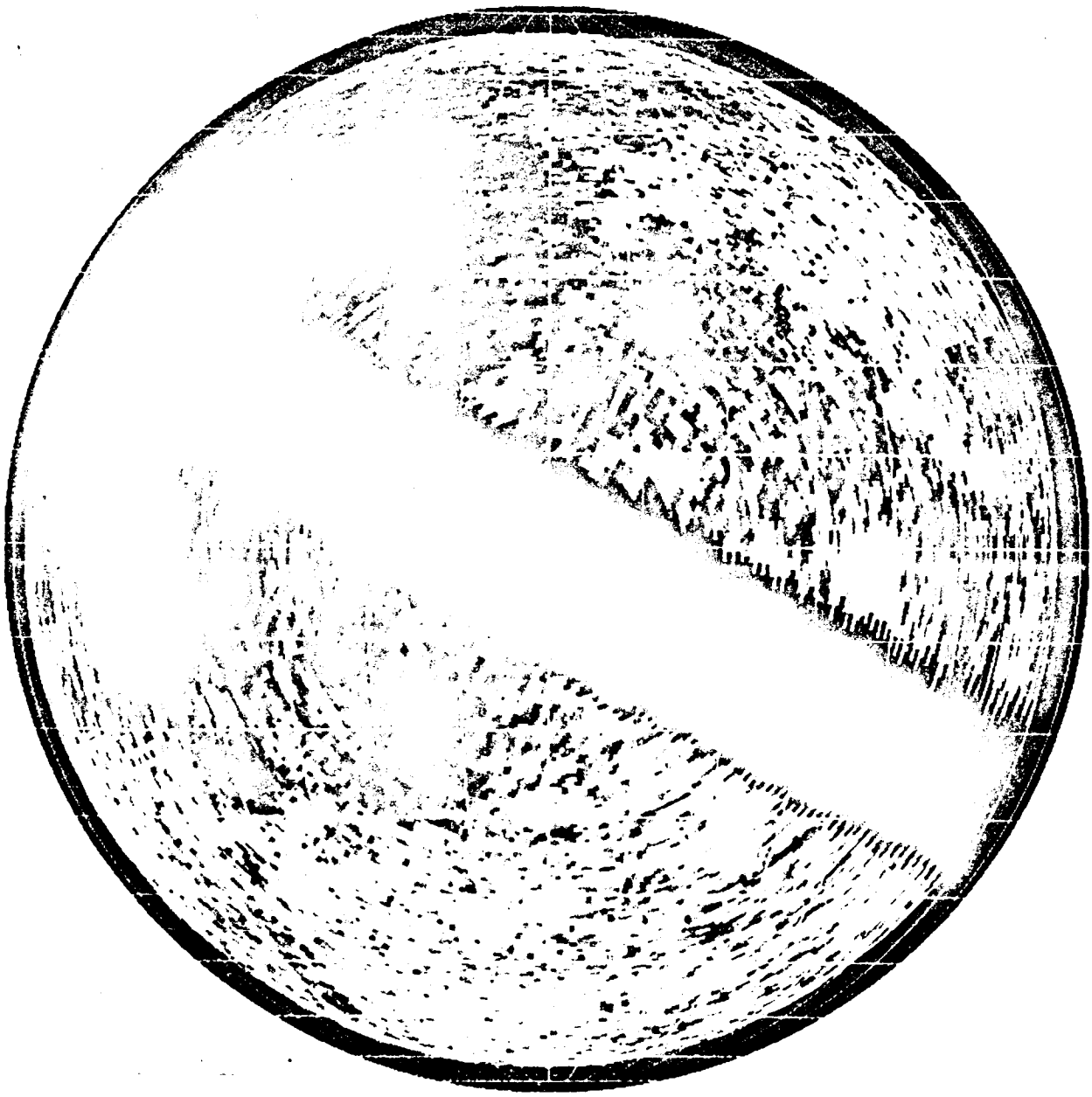
T. W. Thompson, Map of Lunar Radar Reflectivity at 7.5 m Wavelength, Icarus, vol. 13, pp. 363-370.

FIGURE I

Preliminary radar map of the moon at 7.5 m wavelength.

This map shows the departures of radar echo strength from the average for lunar observations at 7.5 m wavelength, the longest wavelength for earth-based observations of the moon. The dark areas are lunar maria which have the weakest echoes. Some highland plains have relatively weak echoes and some craters can be identified. The dark strip across the picture is areas where echoes could not be resolved, and some of this dark strip will be filled in with other observations.

The original observations were made at the Arecibo Observatory, Puerto Rico; the map shows one-fifth of the available data and the display was generated at the JPL Image Processing Laboratory.



PARTICLE TRACK COSMOCHRONOLOGY

NASA Work Unit 195-42-57-01-55
JPL 605-26210-0-8280
E. Haines

OBJECTIVE

The objective of this task is to develop particle track techniques for geochemical and chronological studies, and to apply these techniques to the study of natural systems.

PROGRESS

Fission track activation was used to study uranium concentration and distribution in peridotite inclusions in alkali basalts from six terrestrial localities. These peridotites were gathered from continental, oceanic, and intermediate environments and probably originate in the Earth's mantle. Whole-rock uranium concentrations range from 24 to 82 ng/g (1 ng = 10^{-9} g). In five samples most of this uranium resides in solid solution in the major phases. Minor phases which contain larger than whole rock concentrations include spinel, the hydrous phases phlogopite and hornblende, and glassy veinlets. The veinlets pervade some peridotites and are absent in others. We concluded that: 1) These veinlets are the products of partial melting; 2) The samples are not equilibrated with respect to uranium, and; 3) There is insufficient uranium present to account for oceanic heat flow by conduction alone.

A new particle-track method was developed for measuring very small whole-rock concentrations of uranium. A manuscript is in preparation.

Developmental work on zircons from old (1 to 3 x 10^9 yr) environments showed that their fission tracks records give unreliable ages.

PUBLICATIONS

External Publication

E. L. Haines and R. E. Zartman, "Uranium Concentration and Distribution in Six Peridotite Inclusions of Probable Mantle Origin", Earth Plan. Sci. Letters (accepted for publication).

Meeting Papers

E. L. Haines and R. E. Zartman, "Uranium Total Content and Distribution in Six Lherzolites of Possible Mantle Origin", Trans. Am. Geophys. U. 53 (11), 1129, (1972).

E. L. Haines, "Modeling the Movement of the Pacific Plate With Respect to the Mantle", Trans. Am. Geophys. U. 54 (4), 472 (1973)

OPTICAL ASTRONOMY

NASA Work Unit 196-41-71-01-55
JPL 601-47110-0-8250

R. H. Norton

OBJECTIVE

The long range objective of the Optical Astronomy task is the comprehensive study of planetary atmospheres. Present emphasis is on the spectroscopic investigation of Venus and the outer planets.

PROGRESS

L. Young and A. Young have suggested that one of the constituents of the clouds of Venus could be aqueous H_2SO_4. They arrived at this possibility after being dissatisfied with the agreement between aqueous HCl spectra (Proposed by Lewis) and the spectrum of Venus. In assigning a tentative identification, the Youngs rightly point out that by matching a single feature in the Venus spectrum, in this case, the strong absorption feature at 11.2μ, a unique identification of the cloud composition is not likely.

L. Young, in collaboration with A. Young, J. Young and J. Bergstralh, has discovered a periodicity in the apparent strength of CO_2 absorptions in the spectrum of Venus. The observations were made at Table Mountain Observatory in the course of a multi-observatory study of that planet. Forty spectra were obtained in a run of 20 days. The data, which have appeared in Ap. J. letters, show a cyclic variation of 20 percent in the apparent absorption of CO_2 lines, with a period of four days. The variations are synchronous over the disk, and thus represent a fundamental dynamical mode of the atmosphere.

R. Newburn and J. Bergstralh obtained several dozen spectra of Saturn in their program to monitor the temporal variation of H_2 absorption. Preliminary analysis indicates that some variation does, indeed, exist. A more definitive statement awaits complete analysis of the data, particularly in the area of possible systematic errors.

R. Norton secured four spectra of Uranus in the region of the H_2 (3-0)

band. The plates have been traced but not yet analyzed; all four tracings show clear absorptions by the S(0) and S(1) lines of the band.

The image tube scanner was commissioned in late May 1973. The first observations indicated performance which met all goals but one: sensitivity. Apparently, the gain of the image intensifier section is not high enough for the number of simultaneous channels (1024). Similar conclusions were reached by J. Wampler of Lick Observatory. Nevertheless, the scanner produced spectra 20A wide in 4^{th} order and 28A in 3^{rd} in a time comparable to or slightly faster than photographic recording with an image tube. Specific advantages of the system are: 1) photoelectric linearity, thus avoiding the uncertainties of photographic calibration; 2) the capability to continue an integration until a desired S/N is reached; 3) real-time display of the data. The system was tried for three weeks at TMO and then returned to JPL for modification, principally the addition of a third stage of image intensification.

PUBLICATIONS

External Publications

1. Young, L. D. G. and Young, A. T., "On the Temperature Distribution in a Planetary Atmosphere," Astrophys. J., 176, 533-554, 1972.
2. Young, L. D. G. and Young, A. T., "Comment on the Composition of the Venus Cloud Tops in Light of Recent Spectroscopic Data," Astrophys. J. Letters, 179, L39, 1973.
3. Young, L. D. G., "High Resolution Spectra of Venus," Icarus, 17, 632-658, 1972.
4. Young, L. D. G., Young, A. T., Young, J. W. and Bergstralh, J. T., "The Planet Venus: A New Periodic Spectrum Variable," Astrophys. J. Letters, 181, L5, 1973.
5. Margolis, J. S. and Hunt, G. E., "On the Level of H_2 Quadrupole Absorption in the Jovian Atmosphere," Icarus, in press.
6. Schorn, R. A. and Hunt, G. E., "Venus Cannot be Solved in a Day," Astrophys. J., in press.
7. Bergstralh, J. T., "Methane Absorption in the Atmosphere of Saturn: Rotational Temperature and Abundance from the $3\nu_3$ Band," Icarus, in press.
8. Bergstralh, J. T., "Methane Absorption in the Jovian Upper Atmosphere I. The Lorentz Half-Width in the $3\nu_3$ Band at 1.1μ." Icarus, in press.

9. Margolis, J. S., "The Temperature Dependence of Some Self and Foreign Gas Broadened Lines of Methane," JQSRT, 13, 417, 1973.

10. Margolis, J. S. and Darnton, L., "The Temperature Dependence of the Half Widths of Some Self-and Foreign-Gas-Broadened Lines of Methane," JQSRT, in press.

11. Margolis, J. S., "Line Strength Measurements of the $2\nu_3$ Band of Methane," JQSRT, in press.

12. Bergstralh, J. T., "Methane Absorption in the Jovian Atmosphere II. Absorption Line Formation," Icarus, in press.

Meeting and Symposia Papers

1. Young, L. D. G., "Intensities and Spectroscopic Constants for Some Weak CO_2 Bands," Optical Soc. America, October 17-20, 1972.

2. Schorn, R. A. and E. S. Barker, "Weather on Venus?", DPS, Tucson, Arizona, March 20-23, 1973.

3. Sinton, W. M., "On the Negative Polarization Branch," DPS, Tucson, Arizona, March 20-23, 1973.

4. Young, L. D. G., "Further Observations of Weather on Venus," DPS, Tucson, Arizona, March 20-23, 1973.

5. Younkin, R. L., "The Albedo of Titan," DPS, Tucson, Arizona, March 20-23, 1973.

6. Margolis, J. S., "Some New Laboratory Measurements of the Hydrogen Quadrupole Absorption Lines," DPS, Tucson, Arizona, March 20-23, 1973.

D-34

ENHANCEMENT OF ASTRONOMICAL IMAGES

NASA Work Unit 196-41-71-05-55

JPL 602-47105-0-8240

D. A. O'Handley

OBJECTIVE

The near term objective of this research has been to develop techniques of image restoration capable of recovery of information "lost" as the result of the distorting effects of a turbulent medium and subsequently apply them to images of planetary bodies. The long term objective is the application of these techniques to the general astronomical imaging problem and should permit the achievement of theoretical resolution for large-earth based telescopes.

PROGRESS

In previous research, variations in exposure times were tried in an attempt to minimize atmospheric turbulence. The comparison of a sequence of sunspot negatives taken at typically $1/30^{s}$ or less and $1/30^{s}$ to 1^{s} showed that greater S/N was achieved through short exposures. It was recognized that the combination of large image scale and extremely fine grain emulsion, which was acceptable for the sun and previous work with the moon, is inappropriate for fainter objects of large extent.

A comparison of short exposure times versus medium length exposures has been carried out with the planets Mars and Jupiter, the minor planet Ganymede, and two stars Δ Equlii and 1 Pegusai. Digital image processing, in terms of averaging the random component of the atmospheric transfer function, has been tried through summing in the picture domain or in the Fourier domain. Results were disappointing on Ganymede, however, results on the brighter planets

were improved. The medium exposure gave more subjective improvement.

During this period image enhancement techniques were applied to plates and negatives taken in the past at various observatories. Detail not visible on the originals was restored using digital filtering. The most striking examples are two different exposures of Jupiter, one taken at the coudé focus of the Hale telescope by Professor Guido Munch, and the other taken at the Lunar and Planetary Laboratory of the University of Arizona by Dr. Gerard Kuiper, and an intriguing photo of Venus taken in yellow light by Dr. Kuiper.

Professor Münch's was a single plate taken on IIIa-J emulsion while the remainder were composites involving on the order of 10-20 originals.

These materials were selected because they represented exposures taken during favorable seeing conditions and it was felt that they thus presented the best hope of successful enhancement.

On the other hand, work was also carried out on various composites of Mars kindly supplied by Dr. William Baum from the Planetary Patrol Library. Owing to the relatively poorer seeing conditions, it was not possible to obtain significant improvement on these.

In order to gain more quantitative information about the average transfer function for the turbulent atmosphere, a study was made on three successive nights of single star images obtained at varying zenith angles and exposure times. This work was carried out at the cassegrain focus of the 60 inch telescope on Mt. Wilson and the seeing conditions during all three nights were poor to terrible, as a result of which only limited information was secured.

Nevertheless, it was possible to compare the attenuation of high space frequencies with the overall noise level of the photographic recording and scanning system, including in this instance a single stage magnetically focused image tube, and also compare the transfer function with a theoretical one

obtained from a simple model of a turbulent atmosphere.

The results, obtained for the best seeing encountered during the observations, were that the noise level was approximately two orders of magnitude below the maximum intensity level, and that the transfer curve intersected this noise level at a space frequency corresponding to a resolution of about 1/4 arc second. Thus, high frequency enhancement would permit resolution of perhaps 1/2 arc second with a reasonable S/N ratio.

These figures correspond to single images of course, and one can expect an improvement in S/N ratio of $\sqrt{N}$ by compositing N negatives. This may be done either photographically or digitally. The former is less costly but the latter permits one to average the scanner noise as well and this is important.

In summary, the work to date indicates that meaningful improvement in resolution can be achieved with existing astronomical photographs providing the seeing at the time of exposure was fairly good. Considerable improvement should be possible if large numbers of exposures are composited.

The average processing time per picture, excluding scanning, is approximately 1 hour of IBM 360/44 computer time. As this work progresses from the research phase into more routine application of these techniques, further decreases should be expected.

Contract

This task was cancelled at midyear. The results described above were obtained under a contract to Dr. Paul H. Richter, California State University, Northridge.

Publications

1) Richter, P.H., "Resolution Enhancement of Atmospherically Degraded Astronomical Photographs by Digital Computer Processing," paper 04.02.01, 138th Meeting of the American Astronomical Society, 15-18 August, 1972, East Lansing, Michigan.

GROUND-BASED INFRARED ASTRONOMY

NASA Work Unit 196-41-72-01-55

JPL 602-47210-0-8250

R. Beer

OBJECTIVE

The objective of this task is to obtain and analyze high resolution infrared spectra of the planets in the 1-6μ micron region in direct support of on-going and planned planetary missions.

The primary approach employed is the analysis of spectra produced with a Connes'-type Fourier spectrometer at the 107" telescope, McDonald Observatory, University of Texas.

Ancilliary approaches involve the use of laboratory infrared spectroscopy and data compilations for the analysis of spectra, together with significant operational efforts in the fields of radiative transfer and model atmospheres. Interpretation of the data also feeds back to the development of new instrumentation to support both the present work and potential spacecraft missions. For instance, a spatial-spectral multichannel scanner which operates on the 5μ CH_3D band would be of great value in investigating the cloud morphology of Jupiter both from the ground at low spatial resolution and from a flyby/orbiter at much higher spatial resolution. We propose to construct such a device.

PROGRESS

Venus

The present observing program in the regions of the 1-0 and 2-0 HCl bands was completed on January 1, 1973. The data are currently being reduced and classified. At the same time, J. V. Martonchik is completing his multiple-scattering model atmosphere calculations in an effort to explain the phenomena

observed both by ourselves and other workers. We expect a preliminary report on the results to be ready early in FY 74 and a final report in the form of a paper or papers later in the same year.

Plans are being made for a future observing program, using both the interferometer at McDonald and a new spatial-spectral scanner in an effort to understand the spatial, temporal and phase variations of the HCl and CO_2 on Venus.

Mars

The high-resolution spectra of Mars obtained in 1971 are being prepared for publication. The spectra themselves, both in intensity and in radiometric format (if possible), will be published as a JPL report and any conclusions to be drawn will be published in the open literature. If the radiometric calibrations can be successfully transferred to the data and the AFCRL atmospheric transmission data tapes prove usable, it should be possible to make definitive statements on the global geometric albedo of Mars in the 3-6 micron region, at least on the dates of observation (August 5-6, 1971). We hope that this will complete our observations of Mars.

Jupiter

The 3-6 micron observations of Jupiter have now been published in final form (Beer and Taylor, Ap. J. 179, 309, 1973) and have occasioned considerable cosmological interpretation and activity (Reeves and Bottinga, Nature, 238, 326, 1972; Beer and Taylor, Nature, 240, 465, 1972; Wagoner, Ap. J. 179, 343, 1973; Reeves, Andouze, Fowler and Schramm, Ap. J. 179, 909, 1973).

A number of spectra of Jupiter in the 1-2.5 micron region were obtained in the spring of 1972. Unfortunately, the data tape was inadvertently destroyed before it could be copied and the entire set of observations was lost. We plan

to repeat them in the fall of 1973, particularly in the region of the $2\nu_3$ methane band in an effort to improve our knowledge of the Jovian mixing ratio in this important species.

Saturn

During December 1972, we made our first successful observations on Saturn. We obtained a resolution of 0.5 cm^{-1} in 1.5-2.5 micron region, approximately a factor of 3 higher than that attained by P. Connes. In an effort to determine the origin of the surprisingly large signals obtained, a crude area scanner attachment was made for the interferometer (from a pair of razor blades on a rotatable mount). The tests with this device showed that a considerable proportion of the energy comes from the rings and a significant E-W asymmetry was noted in the output of the rings. Since such an asymmetry is a priori unlikely, we hope to undertake a better analysis using the proposed new spatial-spectral scanner.

Laboratory

The task which used to be separately identified as "Infrared Spectroscopy" (NASA 196-41-74) has been eliminated. In future, we plan to maintain the operational activities of the spectroscopy laboratory under the aegis of this task. It is proposed to employ the services of a Senior Technician or Junior Engineer on a part-time basis to maintain the facility and to assist the users, who will be, in the main, astronomers wishing to obtain laboratory spectra in order to reduce their astronomical data. We hope, in this manner, to make the output of the laboratory more visibly related to the on-going astronomical programs. The facility will, of course, still be available for fundamental spectroscopy and terrestrial-atmosphere related research but such activities will be separately supported.

Analytic Process

It is proposed to employ a programmer/analyst half-time to undertake the task of operating and modifying the reduction routines because we are seriously hampered by delays in producing spectra from our interferograms. These delays frequently extend to a year or more and can only be reduced by the addition of more manpower to this task.

Instrumental

a. Spatial-Spectral Scanner

We had hoped to undertake the development of a spatial-spectral infrared scanner for use at Cassegrain foci in FY 73 but funding cutbacks have made this impossible. We hope, however, to begin such a development in FY 74.

The purpose of the device would be to obtain radiometric and modest spectral resolution data on the planets in a 1-dimensional area scanning mode. Such a device is better than a "pin hole" scanner because the signal/noise ratios are considerably higher and open the possibility of areal multiplexing using moiré grids instead of a slit. The experiments we wish to perform are:

(i) To investigate the morphology of the clouds of Jupiter using the great penetrating power of the 5μ CH_3D bands discovered by us. Such a program would directly support the proposed Mariner Jupiter-Saturn flyby.

(ii) To investigate the spatial, temporal and phase variations of the infrared HCl and CO_2 bands on Venus in the 1.6 micron region in order to elucidate the structure and motions of the clouds of Venus. This would support not only our own analyses, but also those of the Mariner Venus-Mercury mission.

(iii) To investigate the anomalous assymetry in the rings of Saturn referred to earlier. If it should prove to be real, then models of the ring

structure of Saturn will require major revision with a concomittant impact on the proposed Mariner Jupiter-Saturn mission.

(iv) To investigate the predicted limb-brightening in Uranus, based upon the cloud-free model of Belton and Price (Ap. J. 179, 965, 1973). The observation will be difficult but the $2\nu_3$ methane band at 1.6μ may be ideal for the purpose.

The instrument would be relatively straightforward (although of unique design - existing infrared radiometers are unsuitable for the task) and simple to use. It would also be ideally suited for on-line minicomputer operation, although no detailed plans for such an operational mode have been made.

b. Computer-Control of the McDonald Interferometer

The PDP8E computer for this task was delivered nearly 3 months late in the late fall of 1972. Since that time, a major effort was begun on the design of the interfaces and on the programming. Because of serious cutbacks in funding, construction of the primary interface has been slowed and design and construction of the secondary interfaces severely delayed. Our current plans call for completion and installation in October-November 1973, with the system becoming operational by the end of CY 73.

c. Air-Bearing System

An experimental linear motor for the interferometer air-bearing carriage proved to be unsatisfactory and procurement of a replacement was delayed by the funding cutback. When it arrives, a final design for the system will be completed and installation is expected on the same schedule as the computer. This subsystem will increase the speed of the system and double the resolution capability. With

both the computer and the air-bearing, we confidently expect to improve our observing efficiency (actual time integrating energy from the planet/total time at the telescope) by at least 40%.

PUBLICATIONS

External Publications

1. Beer, R. and Taylor, F. W., "Deuterium-Hydrogen Ratio in Jupiter," Nature 240, 465 (1972).
2. Beer, R. and Taylor, F. W., "The Abundance of CH_3D and the D/H Ratio in Jupiter," Ap. J. 179, 309 (1973).
3. Beer, R. and Taylor, F. W., "The Equilibration of Deuterium in the Jovian Atmosphere," Ap. J. Letters 182, L135 (1973).

Internal Publications

1. Beer, R., "The Methodology of Infrared Spectroscopy," in the press.

RADIO ASTRONOMY

NASA Work Unit 196-41-73-01-55

JPL 602-47310-0-8250

S. Gulkis

OBJECTIVE

The objective of this task is to conduct a comprehensive planetary radio astronomy program aimed at providing both observational data and theoretical models which pertain to planetary atmospheres, magnetospheres, and surfaces. Ground based observations of the planets are carried out at the JPL Table Mountain Facility, the Goldstone Deep Space Tracking Stations, the Owens Valley Radio Observatory, and the National Radio Astronomy Observatory.

PROGRESS

Jupiter: Radiation Belt Monitoring Program (Klein)

The program, begun in 1971, to monitor Jupiter's 13 cm flux density was continued during FY'73. The primary objective of the program is to investigate the relationships between Jupiter's synchrotron radio emission, solar activity, and the planets orbital position with respect to the sun, earth, and solar wind. The measurements are made at weekly intervals with the 26-m antenna at the Venus Site, Goldstone, Ca. The 1972-73 data confirm the result seen in the 1971 data, namely that Jupiter's total flux density has decreased by approximately 20% since 1964 and 15% since 1969. No significant short term (weekly or monthly) variations in the flux density have been detected during the $2\frac{1}{2}$ year history of this program.

It is presumed that the long-term variability that has been observed is related to non-equilibrium conditions in Jupiter's radiation belts. To determine the origin of this variability it is very important to continue to monitor the Jovian decimetric radiation over a full cycle of solar activity. The 13-cm monitoring program is being continued in response to this need and to acquire additional data as both conditions of solar activity and the geometrical view-angle of Jupiter change. The time scales of the

variations have not yet been determined. The existence of a simple relationship between Jupiter's flux density and the 10.7 cm solar flux density (which is an accessible index of solar activity) has not been confirmed. If, as is believed, the observed variation is due to a change in the number density or distribution of relativistic electrons, the determination of the time scale may be used to place constraints on the possible mechanism for the acceleration and energy loss which are occurring in the belts.

Data obtained from the monitoring program are used to derive information on Jupiter's magnetic field geometry, the electron pitch-angle distribution in the belts, and the magnetospheric rotation rate. The data are being analyzed to look for time variations in the shape of the beaming curve that describes the dependence of the synchrotron emission on the zenomagnetic latitude and longitude of the earth. Preliminary results suggest that this may also be time variable.

Microwave Spectroscopy of Jupiter and Venus (Klein and Gulkis)

Precision measurements of Jupiter's microwave spectrum were made at 1.25 cm with the 40-m antenna at Caltech's Owens Valley Radio Observatory (OVRO). The JPL tunable receiver was reconfigured to achieve greater sensitivity than was possible with this system in 1971. The search was confined to the frequencies of the inversion doubling transitions at the (1,1), (2,2), (3,3), (4,4) and (4,3) rotational levels of ammonia. No spectral lines greater than 2% were detected either in emission or absorption relative to the continuum. Extremely narrow or very broad features relative to ~50 MHz cannot be excluded, but the emission features that Wrixon tentatively reported in 1971 should have been easily detected in these new data.

Jupiter: Radiation Belt Mapping at 3.7 cm and 11.1 cm (Olsen)

The data taken with the NRAO (National Radio Astronomy Observatory) interferometer during May-July 1972 are in the process of detailed analysis using the JPL scientific computational facilities. The NRAO Fourier inversion programs have been modified to allow maps of the distribution of Jupiter's radio emission to be made at JPL. The data processing to separate the non-thermal and thermal components of the emission has just begun.

Jupiter: Radiation Belt Modeling (Rosenkranz)

A program of modeling the energetic electron distribution in Jupiter's magnetosphere and computing its synchrotron emission was begun. The purpose of this work is to infer information about the electron diffusion process from decimeter wavelength radio observations of Jupiter, by comparing them with the model's predictions.

Venus: Observations at 3.7 cm (Olsen)

Venus was observed with the NRAO interferometer during May and June 1972 primarily for calibration purposes. However, care was taken to observe the planet near the first null of its visibility function and so a determination of the limb darkening at 3.7 cm is available. These data are significant for modeling the absorption in the lower regions of the atmosphere.

Interferometry of Venus (Janssen)

Venus has been observed with radio interferometers at short wavelengths, and the data has provided information on the microwave properties of the lower atmosphere. The University of California's interferometer at Hat Creek was used to observe Venus at 1.35 cm wavelength in September 1972. A computer model for the microwave emission of Venus has been developed as a parallel effort, both to interpret these data and to explore the usefulness of further observations. The structure and bulk composition of the atmosphere is known from spacecraft experiments, and the surface emissivity may be inferred from radar observations. A major unknown to be determined from the passive microwave observations is the source of the atmospheric opacity. The 1.35 cm data, combined with earlier measurements at Hat Creek (Janssen et al., Science 179, 994, 1973), show that the emission from the atmosphere in the neighborhood of the 10 atm pressure level is consistent with absorption by simply the bulk atmospheric constituent CO_2. Additional absorption above this level is constrained by the interferometer data. In particular, water vapor, with a strong line at 1.35 cm is limited to a mixing ratio of 2×10^{-3} in an approximately 10 km layer beneath the

visible cloud tops. This is significantly less than the controversial in situ detections by the Venera atmospheric probes in the same region of the atmosphere. On the other hand, analysis of the 3.7 cm data, taken in 1972 with the NRAO three-element interferometer, shows that there must be a source of opacity in addition to CO_2 in lower layers of the atmosphere, unless either the spacecraft or radar data, or the laboratory data for the CO_2 absorption coefficient are in significant error. The model study also has demonstrated that further interferometric observations at short wavelengths will provide useful information on the quantity, altitude distribution and frequency dependence of the additional absorption if it is indeed verified to be present. Observations at 8 mm at Table Mountain, and more extensive observations in the spectral range 1.2 - 1.5 cm at Hat Creek, are planned for the time of the next conjunction (January 1974).

64-Meter Observations of Jupiter, Saturn, and Uranus (Gary)

Approximately 15 hours of time on the Goldstone 64-meter antenna were used to observe Jupiter, Saturn and Uranus at λ2.07 cm (14.5 GHz) and Saturn at λ3.65 cm (8.4 GHz), which has led to the following disk temperature determinations: Jupiter (λ2.07 cm) = 173.4 ± 5.2°K, Saturn (λ2.07 cm) = 162.3 ± 3.8°K, Uranus (λ2.07 cm) = 178.7 ± 12.9°K, and Saturn (λ3.56 cm) = 169.7 ± 2.3°K. The thermal component of Jupiter's emission is thought to contribute 97% of the observed value or 168.6 ± 9.9°K, which is more than 20% higher than the observed temperature near 1.25 cm (24 GHz). This result is in agreement with model atmosphere calculations and other observational data that indicate the existence of a pressure-broadened spectral feature due to absorption by ammonia near 1.25 cm wavelength.

The Saturn disk temperature measurements are slightly higher (1σ) than those observed when the rings were seen edge-on in 1966. This result is interpreted in terms of an optically thick ring system (as required by their high radar reflectivity) and a low microwave emissivity of the ring particles. A microwave emissivity of 0.31 ± 0.14 at λ3 cm is derived. The Uranus measurement gives support to the slowly emerging microwave spectrum wherin the disk temperature drops from ~190°K in

the wavelength region λ2 cm to ~140°K at λ1 cm. The explanation of this is likely to invoke absorption by atmospheric ammonia as in the case of Jupiter and Saturn.

TMO Planet Monitoring Program (Gary)

The ongoing program to monitor Venus, Jupiter, and Saturn at λ0.9 cm was interrupted for concentrated observations of Venus during the conjunction of 1972. The emphasis on Venus was motivated by the dual desires of making high precision determination of the currently disputed microwave phase effect and of searching for small, short-term departures from any perceived phase effect that might be attributed to possible changes in the Venusian cloud cover. The Venus observations were thwarted just before conjunction by a lightning strike, which caused extensive damage to equipment. The Venus data that were obtained show no evidence for day-to-day or weekly changes exceeding about 1.5%. A least squares fit to all the TMO data accumulated since 1971.5 leads to a sine-curve phase effect given by:

$$T_D[^\circ K] = 448.1 + 5.4 \cos(\theta - 190^\circ).$$
$$\pm 2.4 \quad \pm 3.7 \qquad \pm 27^\circ$$

This corresponds to the night side appearing warmer than the day side (inverse phase effect) by 10.5 ± 7.4°K. Although the uncertainty of the measurement is large, it is reasonable to conclude that it negates many of the earlier claims that the phase effect was much larger than 10°K and of the opposite sign (daytime warmer).

Jupiter observations were resumed in February 1973 after a one year hiatus. The recent observations show Jupiter's disk temperature to be the same as in 1971. The average value is 145.5 ± 0.9°K, where the SE of 0.9°K (0.6%) represents the formal statistical error.

Saturn's disk temperature seems to have increased from 1971 to 1973 by an amount which has marginal statistical significance, from 134.0 ± 5.4°K to 147.0 ± 4.0°K (a 2 σ difference). The average value of Saturn's disk temperature during this period was 142.4 ± 3.2°K.

An analysis of the 2 years of intensity measurements of the radio sources Cas A and Tau A have led to the determination of a Cas A decay rate of 0.7 ± 1.0% year, which agrees well with extrapolations from longer wavelengths. Of greater significance, perhaps, is the support that this agreement gives to the idea of Tau A having long-term constancy, which was recently in dispute. This long-term constancy is important in interpreting the planet monitoring observations.

A re-calculation of the TMO flux scale, inspired by recent high frequency absolute measurements of Cas A by Wrixon et al., suggests that the antenna 2-horn aperture efficiency is 0.925 instead of the 0.95 used from 1971 to the early-1973. The disk temperatures reported here are on the new flux scale, and it should be noted that the TMO temperatures of Venus and Jupiter now agree quite well with model atmosphere calculations.

Uranus: Determination of Brightness Temperature at 1.3 cm (Olsen and Klein)

During July 1972 and May 1973, Uranus was observed using the 130-ft. telescope at the Owens Valley Radio Observatory. The objective was to accurately determine the thermal radio flux from the planetary disk. Preliminary analysis of the two sets of data indicates that Uranus has been detected with a signal-to-noise ratio greater than 10.

Callisto: Observations at 2.07 cm (Olsen)

During the period August-October 1972, Callisto (J IV) was observed using the 210-ft. telescope at Goldstone in an attempt to determine the brightness temperature of this satellite. No detection was made, but an upper limit to the brightness temperature of 250K was determined. An equipment malfunction caused the system sensitivity to be poorer than normal during the observing period.

PUBLICATIONS

Meeting and Symposia Papers

1. Janssen, M. A., "Radio Interferometric Observations of Venus near 1.35 cm Wavelength-Implications for the Middle Atmosphere," presented at the AAS-Division for Planetary Sciences Annual Meeting held in Tucson, Arizona, March 1973.

2. Klein, M. J., "Broad-Band Measurements of the Jovian Spectrum from 20-24 GHz," presented at the AAS-Division for Planetary Sciences Annual Meeting held in Tucson, Arizona, March 1973.

3. Gulkis, S., Klein, M. J., Poynter, R. L., and Read, R. B., "A Search for Narrow-Band Ammonia Lines in the Jovian Microwave Spectrum," presented at the AAS-Division for Planetary Sciences Annual Meeting held in Tucson, Arizona, March 1973.

4. Carpenter, R. L., Gulkis, S., Sato, T., and Pigg, J. C., "A New Upper Limit to the Small Scale Spatial Variations in the Microwave Cosmic Background Radiation," presented at AAS-Division for High Energy Astrophysics Meeting held in Pasadena, CA, October 1972.

5. Klein, M. J., "Flux Density Measurements of Selected Radio Sources Relative to Cas A at 2.18 GHz," presented at U. S. Commision V URSI Meeting held at Socorro, New Mexico, January 1973.

6. Gulkis, S., "Evidence for Deep Convection from Radio Observations," presented at meeting on Dynamics of the Jovian Atmosphere held at Flagstaff, Arizona, November 1972.

External Publications

1. Newburn, R. L. and S. Gulkis, "A Brief Survey of the Outer Planets Jupiter, Saturn, Uranus, Neptune, Pluto, and their Satellites," Space Science Reviews, 3, 179-271 (1973).

2. Gulkis, S., and R. Poynter, "Thermal Radio Emission from Jupiter and Saturn," Proceeding of Conference on Physics of the Earth and Planetary Interiors, Lunar Science Institute, Houston, Texas, published by North Holland Publishing Company, North Holland, Amsterdam, in press (1973).

3. Gulkis, S., Gary, B., Klein, M. and Stelzried, C., "Observations of Jupiter at 13 cm Wavelength During 1969 and 1971," Icarus 18, 181-191, February 1973.

4. Gulkis, S., "Thermal Emission from the Major Planets, "Space Science Reviews, in press (1973).

5. Hills, J. G. and Klein, M. J., "On the Observed Deficiency of Ionized Gas in Globular Clusters and the Companions of M31." Astrophys. Letters 13, 65-68, (1973).

6. Klein, M., Gulkis, S. and Stelzried, C. T., "Jupiter: New Evidence of Long Term Variations of Its Decimeter Flux Density," Ap. J. (Letters) 176, L85-L88, September 1972.

7. Carpenter, R. L., Gulkis, S., and Sato, T., "Search for Small Scale Anisotropy in the 2.7°K Cosmis Background Radiation at a Wavelength of 3.56 cm," Ap. J. (Letters) 182, L61-L64, June 1973.

8. Gary, B. L. et al. "3C120, BL Lacertae, and OJ287: Coordinated Optical, Infrared, and Radio Observations of Intraday Variability" Ap. J. (Letters), 178, L51-L59, December 1972.

9. Gary, B., Olsen, E. T., and Rosenkranz, P. W. "Radio Observations of Cygnus X-3 and the Surrounding Region" Nature 239, p. 128, October 23, 1972.

DSIF RADAR ASTRONOMY SUPPORT

NASA Work Unit 196-41-73-01-05

JPL 602-47321-0-8230

T. W. Thompson

OBJECTIVE

In this task, radar maps of Venus obtained by JPL's Goldstone Radar Facility are being examined to refine the Venusian rotation rate and spin vector direction.

PROGRESS

Computer programs have been written to cross correlate Venus features seen on several different days during the 1969 and 1971 inferior conjunctions. Fifteen features have been identified for correlating on different days. Unfortunately, this task was canceled before results were obtained.

PLANNED ACTIVITIES

None, task canceled.

PUBLICATIONS

None.

DSIF Radar Astronomy

NASA Code 196-41-73-02-00

JPL Code 602-47320-0-3310

R. M. Goldstein

Objective: The general objective of this work unit is to use the unique transmit/receive capabilities of the DSIF to determine properties of the surfaces and orbital elements of the radar-accessible planets. These planets currently include Mercury, Venus, Mars, Earth-grazing asteroids, a few of the Jovian moons, and Saturn's rings. Such radar data provides radar brightness maps, altitude contours and profiles, scattering laws, orbital element corrections, and in some cases rotation vectors. This data provides valuable planetology and celestial mechanics in its own right, enhances spacecraft data interpretation from ongoing missions, and is factored into planetary program pre-mission planning in science, navigation, and communications. It is the specific objective of this work unit to turn raw doppler, range, and in some cases interferometer fringe data obtained from the DSIF 64m station, DSS 14, the Mars site, sometimes in conjunction with DSS 13, the Venus site, a 26m antenna, into scientifically useful data about the planetary target.

Progress: Processing of Mars radar data was completed, yielding over 6000 altitude points and backscattering functions. This data was used for bench marks by the Mariner 9 working group on topography.

Scattering properties of Toro, a small asteroid which passed within 20 million km of Earth, were successfully measured. Radar and optical data, combined, indicate that the radius of Toro is about 2.3 km, that Toro is irregular and that the surface is somewhat smooth (to the scale of the wavelength, 12.6 cm).

DSIF Radar Astronomy
NASA Code 196-41-73-02-00
JPL Code 602-47320-0-3310
R. M. Goldstein

Progress: (Cont'd.)

Echos from the rings of Saturn have shown that the particles are extremely efficient radar reflectors ($\sigma \geq 60\%$). It follows that the particles are likely to be rough, with diameters on the order of a meter or larger. Depending on the density with which the rings are filled, rocky or metallic chunks would fit the data well.

A high resolution radar brightness and altitude map was produced for a small area (1500 km disk) on Venus. Ten km surface and 200m altitude resolution was obtained. This part of the surface, at least, is covered with craters. The largest is 160 km across, but only 400m deep. The area is quite flat; the peak to valley distance being less than 1 km.

Some 3 dozen radar range measurements to the front surface of Mercury and/or Venus were supplied to the orbit determination group. This data will be used to improve the ephemerides of Earth, Venus and Mercury for the MVM'73 project.

Plans:

Range measurements to Venus and Mercury will continue on as regular a basis as possible. High resolution radar images and altitude profiles (albeit without solution of the north-south ambiguity) will be attempted for Mercury.

Mars radar measurements will be repeated this summer for the Viking project. The belt scanned will be south of the previous one, but with some overlap. Simultaneous observations with Haystack and Arecibo

may prove helpful to Viking in interpreting radar scattering data.

A dozen high resolution, partly overlapping radar brightness and altitude images of Venus will be attempted this winter. The results are expected to be useful for the MVM'73 project.

External Publications:

"Review of Surface and Atmospheric Studies of Venus and Mercury", R. M. Goldstein, Icarus, Vol. 17, pp. 571-5, 1972.

"A Radar Image of Venus", R. M. Goldstein, H. C. Rumsey, Icarus, Vol. 17, pp. 699-703, 1972.

"Mars Topography and Surface Properties as Seen by Radar: the 1971 Opposition", G. S. Downs, R. M. Goldstein, R. R. Green and G. A. Morris, Icarus, Vol. 18, pp. 8-21, 1973.

"Radar Observations of (1685) Toro", R. M. Goldstein, D. B. Holdridge and J. H. Lieske, Astronomical Journal, in press.

MICROWAVE RADIOMETER DEVELOPMENT (MRD)

NASA WORK UNIT 196-41-73-03-55

JPL 602-47330-0-8230

F. S. Soltis

OBJECTIVE

The objectives of this task are to design, develop, construct, test and maintain advanced microwave radiometer systems for use at the Table Mountain, Goldstone, Owens Valley and other radio telescope facilities. This work is in support of the Radio Astronomy Task - NASA 196-41-73-01-55.

PROGRESS

During FY'73, efforts were concentrated in four primary instrument development programs, each aimed at providing new or improved instrumentation for the Radio Astronomy Task (196-41-73-01-55). These are:

A. 8mm interferometer
B. 8mm receiver system
C. 13mm tunable receiver
D. Multichannel data system

Interferometer

Progress has been made toward the construction of an 8mm wavelength interferometer at Table Mountain. The interferometer will consist of the existing 5.5 meter antenna coupled as a Michelson stellar-type interferometer with a 3-meter antenna on an east-west baseline. Two sites have been prepared for the 3-meter antenna, which will provide spacings of 65-meter and 130-meter. Underground cabling has been laid to provide all necessary interconnection between these sites, the 5.5 meter antenna, the laboratory building, and a van which will contain interferometer instrumentation and the 3-meter antenna drive control hardware. A Nike tracking pedestal has been modified to enable the 3-meter antenna to track astronomical objects. All components of the interferometer have

been or will soon be completed. These include the variable IF delay system and the IF equalizers and correlator, the LO distribution system, a receiver front end which will be mounted at the prime focus of the 3-meter antenna, computer interfacing hardware, and the computer control and the data processing program. Final installation at Table Mountain is scheduled for September 1973 to be followed by tests of the completed interferometer on astronomical sources.

8mm Receiver System

The 8mm radiometer used on the 5.5-m radio telescope at Table Mountain was routinely maintained. The system performance was upgraded with the addition of equalization networks in the I.F. system. A computer controlled system for varying the receiver local oscillator frequency was designed, fabricated, and installed.

13mm Tunable Receiver

A phase-locked local oscillator was installed in the 13mm tunable radiometer. This improved the receiver performance as a result of lower local oscillator noise, and also allows the receiver frequency to be set precisely.

Multichannel Data System

Design and fabrication of a 64-channel data system was accomplished. Interfaces were included for either a programmable calculator or computer to provide real-time data processing. This system was used at Owens Valley Observatory with the 13mm radiometer and multichannel I.F. amplifier assembly for planetary line work.

PUBLICATIONS

None.

INFRARED SPECTROSCOPY

NASA Work Unit 196-41-74-01-55
JPL 602-47410-0-8250

R. Beer

OBJECTIVE

The objective of this task is to support the on-going programs of planetary spectroscopy by providing the necessary supporting laboratory data on line/band strengths and widths of known molecules and as an aid to the identification of unknown features.

The principal instrumentation employed is a 1.8 meter vacuum scanning spectrometer coupled to a 2-meter multitraversal absorption cell capable of providing path lengths up to a few hundred meters at several atmospheres pressure. Other smaller and larger cells are available for special purposes. The laboratory also maintains a Beckman IR 12 infrared spectrometer.

Coupled to the task is an extensive file of reprints of published high-resolution spectra and related data, now containing over 2000 entries, which plays a large role in the better utilization of the spectroscopy laboratory.

This task has now been eliminated and the personnel either laid off or transferred into other tasks. However, the spectroscopy laboratory is still in existence and will henceforth be maintained under other tasks.

PROGRESS

The analysis of the temperature dependence of methane absorptions has continued and new values for the line strengths of the H_2 fundamental quadrupole vibration-rotation band have been produced.

A low resolution study of the infrared absorption of HCl and H_2SO_4 solutions has been made as an aid to understanding the observed infrared spectrum of Venus.

The absorption strengths of 28 of the strongly allowed manifolds of the $2\nu_3$ band of CH_4 have been measured. It is demonstrated that the intensity pattern does not follow the prediction based on rigid rotor formulae. The deviations are important in the determination of rotational temperatures by means of the CH_4 spectra.

PUBLICATIONS

External Publications

1. J. S. Margolis "The temperature dependence of some self and foreign gas broadened lines of methane", JQSRT (in the press).
2. J. S. Margolis and G. E. Hunt "On the level of H_2 quadrupole absorption in the Jovian atmosphere", Icarus (in the press).
3. J. S. Margolis "Line strength measurements of the $2\nu_3$ band of CH_4", JQSRT (in press).
4. G. E. Hunt and J. S. Margolis "Formation of spectral lines in planetary atmospheres V. Collision narrowed profiles of quadrupole lines in H_2 atmospheres," JQSRT 13, 417 (1973).

Meeting and Symposia Papers

1. J. S. Margolis "Some new laboratory measurements of the hydrogen quadrupole absorption lines", AAS Division of Planetary Sciences, Tucson, Arizona, March 1973.
2. J. S. Margolis and Y. Y. Kwan "The measurement of the absorption strengths of some lines in the $\nu_1 + \nu_2$ and $\nu_2 + \nu_3$ bands of ammonia", 28th Symposium on Molecular Structure and Spectroscopy, The Ohio State University, Columbus, Ohio, June 11-15, 1973.

AIRBORNE INFRARED ASTRONOMY

NASA Work Unit 352-02-03-02-55

JPL 611-20311-0-8250

H. H. Aumann

OBJECTIVE

The long range objective of this task is to study the composition and temperature structure of the atmospheres of the planets Venus, Jupiter and Saturn. To this end planetary spectra between 5μ and 100μ with approximately 1 cm^{-1} resolution will be obtained using a Michelson interferometer on board the C141 Airborne Infrared Observatory.

PROGRESS

A Michelson interferometer, equipped with a liquid Helium cooled bolometer detector, has been adapted for use on the C141 telescope. The first checkout of the complete interferometer system in the 8μ to 13μ telluric window, using the 24" Mt. Wilson telescope, has been highly successful and has proven the basic soundness of operating an interferometer with a dual beam (thermal background subtracting) wobbling secondary mirror chopper. Spectra of the Sun and the Moon with 0.5 cm^{-1} and of Venus with 2 cm^{-1} resolution have been obtained. The system sensitivity, referred to the telescope aperture, is $5 \times 10^{-16} \frac{\text{watt}}{\text{cm}^2\ \text{Hz}^{\frac{1}{2}}}$. The interferometer is, at present, equipped with a KBr beam splitter, which limits its wavelength range to the 5μ to 25μ region. If the above sensitivity can be achieved in the C141, the following signal to noise ratios can be

expected for spectra with 2 cm^{-1} resolution:

Venus (7 - 14μ)	S/N > 100
(14 - 25μ)	S/N > 100
Jupiter (7 - 14μ)	S/N ~ 50
(14 - 25μ)	S/N > 100
Saturn (7 - 14μ)	S/N ~ 1
(14 - 25μ)	S/N ~ 100

The observing time per spectrum is 3 minutes. The system has sufficient sensitivity to permit observations of targets of opportunity such as bright asteroids or comets. We estimate the achievable signal-to-noise ratio with 2 cm^{-1} resolution for the Comet Kohoutek 1973f for 7 to 25μ observations to be approximately 30.

PUBLICATIONS

None.

PRECISION LUNAR EPHEMERIS

NASA RTOP 383-09-51
JPL 608-25110-0-3910

J. G. Williams

OBJECTIVES

The objectives of this program during FY'73 were to provide high accuracy range predictions to McDonald Observatory, to improve lunar physical librations principally through numerical integrations, and to fit optical and laser range observations as a means of improving the lunar ephemeris.

PROGRESS

Range Predictions

High accuracy range predictions have been routinely supplied to McDonald Observatory as card decks of Chebyshev polynomials for each night. LE18 has been the prediction ephemeris. Predictions have been made for the retroreflectors left during the missions of Apollo 11, 14 and 15 and Lunokhod 1 and 2.

Physical Librations

The past year has seen a striking improvement in our understanding of lunar physical librations. These improvements in libration theory have led to improvements in the comparison between analytical librations and numerical integrations and they have led to steadily shrinking residuals in the fits to the laser range data.

The first improvement was discovered by D. H. Eckhardt (AFCRL) and W. M. Kaula (UCLA). Contrary to expectations it was found that the third degree harmonics of the moon's gravitational field give rise to large effects in the librations. One sizable second-order term due to third harmonics was developed by us and added to the first-order theories of Eckhardt and Kaula.

A major effort was made in developing libration terms arising from the additive and planetary terms in the lunar theory. All of these terms save one had not been calculated before. One pair of these terms cause 70 m deviations in the latitude. Two resonant terms were found in the longitude. In all, terms with 23 different periods with amplitudes $\geq 0.07''$ (0.6m) have been calculated.

The program which numerically calculates the lunar physical librations has been steadily upgraded during the past year. For example the calculation of the additive and planetary terms in libration allowed the analytical lunar ephemeris to be replaced by numerically integrated ephemerides for the moon.

The numerically integrated librations must still be fit to analytical libration theories as a means of suppressing unwanted free librations. One of the modifications made during the past year allows the partial derivatives with respect to the starting conditions to be saved on tape rather than recalculated each time. This improvement cut the execution time of the program by a factor of four. Another modification now allows fits of the integration to the theory over any time span rather than the previous limit of three years.

When D. H. Eckhardt's (1970) second-degree theory plus our terms due to additive and planetary terms are used as the analytical theory to be compared with a three year numerical integration an rms fit of 0.3" (2.5m) results. When third degree effects are included in both the theory and the numerical integrations the fit gets three times worse. This indicates that the present analytical theory for the third degree terms is not as good as that for second degree terms though this should soon change.

The above results have been written up and will be published in The Moon. These results were described at the Lunar Dynamics and Observational Coordinate Systems meeting in January and at the American Geophysical Union meeting in April.

Very recently it was found that the effects of working in a precessing coordinate system are more important than was thought. These effects have not been previously included in either analytical or numerical work. The precession of the coordinate system causes a 5" shift in the inclination of the lunar equator which will effect our determination of β. The influence of these non-inertial terms has not been completely analyzed yet. Like several other effects the importance of these terms was found when the non-inertial terms in the differential equations were added to the numerically integrated librations program as a refinement.

Data Analysis

Virtually all of the changes made in the analysis of lunar laser ranging data during the past year has been in the libration routines. Nearly all of the mysterious 10 m signatures that we had at this time

last year were due to the previously discussed libration effects. Over a fit to three years of ranging data ending in June 1972 the effects of various states of libration theory and the rms range error are as follows: second degree terms plus two additive terms gives 10 m, including additive and planetary terms yields 6m, adding third and fourth degree harmonic terms (fixed) gives 4m, and finally using P. Bender's (JILA) adjusted third degree harmonics results in 3m fits. The above results were reported at the Division on Dynamical Astronomy meeting in June.

Our present effort is directed toward replacing the analytical theory in our analysis program with the results from the program for numerically integrated librations. Very preliminary results indicate that at least a factor of two improvement in the fits will result from this change.

A joint project between P. Bender (JILA), J. D. Mulholland (University of Texas) and ourselves was carried out to determine the distance of McDonald Observatory from the spin axis of the earth using data near zero declination. Results were compatible with the survey tie to the Smithsonian Astrophysical Observatory Baker-Nunn station at Oregon Pass, New Mexico. These results were reported at the American Geophysical Union meeting in San Francisco in December.

Very low priority was given to the analysis of optical data. Some programming modifications were made to allow for the difference between the center of mass and the center of figure of the moon. No joint range-optical solutions have been tried yet.

New Ephemerides

During the past year six numerically integrated lunar ephemerides have been generated. LE22, LE23, and LE24 are a sequence of ephemerides generated from P. Bender's starting conditions. At this point the error in the earth's

figure calculations in the integrator was found and fixed. LE25 was a fairly successful attempt to correct the LE24 starting conditions for the integrator error. LE26 was an integration designed for a check case with J. D. Mulholland. LE27 was an integration based on starting conditions solved for at JPL.

MEETING ATTENDANCE

1. LURE Team meetings: July 24-25, 1972, October 30-31, 1972, February 6-7, 1973, June 18-19, 1973. Special LURE subgroup meeting May 14-15, 1973.
2. American Geophysical Union Meeting, San Francisco, December 4-6, 1972.
3. Lunar Dynamics and Observational Coordinate Systems (International Astronomical Union Colloquium Number 24), Houston, January 15-17, 1973.
4. American Geophysical Union meeting, Washington, D.C., April 16-19, 1973.
5. American Astronomical Union Division on Dynamical Astronomy meeting Cincinnati, June 21-23, 1973.

PUBLICATIONS

1. Spin-Axis Distance of the McDonald Observatory (abstract), J. G. Williams, J. D. Mulholland and P. L. Bender, Eos 53, 1972.
2. Lunar Physical Librations and Laser Ranging, J. G. Williams, D. H. Eckhardt, W. M. Kaula, and M. A. Slade, The Moon, in press.
3. Reduction of Lunar Laser Ranging Data as Applied to the Physical Librations and Ephemeris of the Moon (abstract), W. S. Sinclair, Bulletin of the American Astronomical Society, in press.

LUNAR SCIENCE STUDIES

NASA Work Unit 383-09-55-03-00

JPL 608-55513-0-1310

R. G. Brereton

OBJECTIVES

The Lunar Science Studies task is a cooperative effort between the Lunar Exploration Office (SM) of NASA and the Advanced Technical Studies Office of JPL to provide accurate and timely lunar science information and to provide a synthesis of lunar scientific data. The specific objectives of the task are as follows:

1. To acquire lunar scientific information from all possible sources (NASA-SM, JSC, scientific literature, scientists, etc.) and then synthesize this into documents suitable for use by NASA and others.
2. To provide information and assessment of the Soviet lunar exploration program.
3. To provide lunar science planning data for the Lunar Exploration Office (SM) of NASA.

In accordance with the above objectives for this task, the following accomplishments are noted:

1. Participated in Post-Apollo Lunar Science Summer Study. A document entitled Post-Apollo Lunar Science Objectives (32 pages) was prepared for this meeting.
2. Participated in the preparation and review of material used by the Lunar Exploration Office (SM) for their 1973 Congressional submission. An internal document entitled "1973 Congressional Submission," which contained a collection of material regarding the current scientific results from Apollo and an assessment of the Soviet lunar program, was submitted in October 1972 as a preliminary step.
3. Provided information on USSR lunar program to NASA in numerous informal communiques and in internal publication entitled, "Soviet Lunar Exploration (Accomplishments and Intent)" 5/7/73.

4. Provided ad-hoc science support to Lunar Exploration Office (SM) for planning. Specific work items here resulting in a formal internal publication were:

   A. Work Statement for Lunar Orbiter Study 9/28/72.

   B. Goals and Objectives "Lunar Program Plan" 3/14/73. This was a straw-man document to assist SM in preparation of "Lunar Program Goals" 3/26/73.

   C. Lunar Exploration and Utilization to 1990. This document outlines objectives, systems and technology for future exploration and utilization of the moon.

EXTERNAL PUBLICATIONS

1. Post-Apollo Lunar Science, Report of a study by the Lunar Science Institute, Houston, Texas, July 1972. et al contributor.

D-44

MARS PHOTOGEOLOGY INTERPRETATION

NASA Work Unit 384-50-71-01-55
JPL 609-57110-0-8260
R. S. Saunders

OBJECTIVES

The objectives of this task are to 1) delineate the major crustal provinces of Mars, 2) infer the physical processes that act at the surface of Mars, 3) determine the nature of the surface materials, and 4) construct the geologic history by identifying the sequence of events that led to the present condition of the surface of Mars.

Photogeologic analysis of Mariner 9 pictures provides the basic data for this task. Other data have been incorporated where they bear directly on interpretation of crustal geology and structure. Gravity data provided by the Celestial Mechanics Experiment of Mariner 9 have been particularly useful. Earth-based radar data have been combined with radius determination from the Mariner 9 Radio Occultation Experiment to provide topographic information.

PROGRESS

A preliminary map of Mars' geologic provinces was compiled from Mariner 9 pictures. A preliminary version of the geologic map of MC-19 was completed and submitted to the U. S. Geological Survey, Flagstaff, for open-file. Programs were developed (a joint effort with T. A. Mutch, Brown University) to allow direct analysis of Mariner 9 pictures by using a digitizer. As my part of the joint task, structural features were digitized by category: scarp, furrow, graben, etc. Programs have been written to plot these structural features and construct azimuth-frequency diagrams to facilitate the analysis of the data.

Earth-based radar data were adjusted to Mariner 9 radio occultation radii, and topographic maps were constructed for most of the surface of Mars. These maps were used to estimate regional slope to determine whether the major river-like features of Mars have regional gradients consistent with the fluvial hypothesis. The topographic maps were also used to prepare a Bouguer anomaly map of Mars in combination with gravity data provided by the Celestial Mechanics experiment. The most significant finding of the synthesis of topographic, gravity, and photogeologic evidence is that the Tharsis region is at least partly compensated with less dense material as a "root". The photogeologic analysis of the regional structures suggests that the Tharsis ridge is an uplifted dome. Although we are still in a preliminary stage of the analysis, it appears certain that the combined data of geophysics and photogeology are providing a consistent and revealing view of the crustal structure of Mars.

PUBLICATIONS

External Publications

Phillips, R. J., Saunders, R. S., and Conel, J. E., Mars: Crustal Structure Inferred from Bouguer Gravity Anomalies: J. Geophys. Res., (in press), 1973.

Carr, M. H., Masursky, H., and Saunders, R. S., A Generalized Geologic Map of Mars: J. Geophys. Res. (in press), 1973.

Meeting and Symposia Papers

Saunders, R. S., and Gillespie, A. R., Interpretation of Mars Surface Features from Analysis of Local Color Variations Using Mariner Mars 1969 Multispectral Television Pictures (Abs.): 24th International Geological Congress, Planetology Section, p. 30, 1972.

Saunders, R. S., Conel, J. E., and Phillips, R. J., Mars: Geologic Interpretation of Tharsis Bouguer Gravity Anomalies: American Astronomical Society, Division of Planetary Sciences, Annual Meeting, 20-23 March, 1973 (Abstract to be published in AAS Bulletin).

Saunders, R. S., The Furrowed Terrain of Mars: American Astronomical Society, Division of Planetary Sciences, Annual Meeting, 20-23 March, 1973 (Abstract to be published in AAS Bulletin).

Phillips, R. J., Conel, J. E., and Saunders, R. S., Isostatic Models for the Martian Crust: American Geophysical Union, Annual Meeting, April 16-29, 1973.

MAGNETOMETER DATA ANALYSIS: POST PROJECT SUPPORT

NASA Work Unit 385-36-01-01-55
JPL 610-30010-0-8280
E. J. Smith

OBJECTIVE

This task provides for analysis and interpretation of scientific data obtained by the Ogo search coil magnetometer and the Mariner vector helium magnetometer (VHM).

PROGRESS

Extremely low frequency (10-1000 Hz) electromagnetic emissions in the midnight sector of the outer magnetosphere have been studied using OGO-5 search coil magnetometer data. Chorus was detected in conjunction with magnetospheric substorms throughout the regions from L = 5 to 9 but only during post midnight hours. No chorus was seen in the three hours preceding local midnight even when substorms were in progress. The post midnight chorus occurred only with $\pm 10^{o}$ of the geomagnetic equator and was observed most frequently at the equator. Time averaged intensities varied from 10^{-8} to 10^{-6} γ^2/Hz, more than an order below the maximum values reported previously for the dayside chorus.

The chorus occurred in narrow frequency bands having a bandwidth between 50 and 200 Hz. Chorus frequencies varied from less than one-fourth to as high as three-fourths of the equatorial electron gyro frequency. All frequencies in this range were detected except for a narrow band near one-half the electron gyro frequency where the chorus

appeared to be strongly attenuated. Chorus was often observed as two distinct bands above and below one-half the gyro frequency. The two most common types of chorus were found to be narrow band chorus without structure and falling tones. Rising tones and hooks were also observed.

Temporal variations were observed in the form of pulsations, often with quasi-periods of 5-15 seconds, although quasi-periods as short as three seconds and as long as minutes were observed. Variations of the ambient magnetic field measured by an onboard magnetometer were examined but no apparent correlation between micropulsations in the field and the chorus pulsations was detected.

Many features of post midnight chorus can be accounted for by a cyclotron resonant interaction between the waves and electrons injected into the magnetosphere from the geomagnetic tail during substorms. The distribution of the chorus in the magnetosphere as a function of local time and L is strikingly similar to the distribution of enhanced, trapped and precipitated electrons with energies > 40 keV that are observed during magnetospheric substorms. The strong local time asymmetry in the chorus distribution may be attributed to the curvature and gradient drift of the injected electrons toward local morning hours. Cyclotron resonant interactions would be expected to be strongest near the equator, where the resonant electron energy is minimal, as observed. The confinement of the signals to within 10° of the equator, is attributed to Landau damping by low energy (1-10 keV) auroral electrons as the waves propagate away from the equator and their direction of propagation deviates from the ambient field direction. The attenuation band at one-half the electron

gyro frequency is thought to be the result of Landau damping by electrons whose energy is the same as those electrons which are in cyclotron resonance with the chorus at that frequency but which are traveling in the same direction as the waves.

A close correspondence probably exists between the occurrence of midnight and dayside chorus. The maximum in chorus intensity at approximately 10 hours local time, which is correlated with the dayside maximum of energetic electron precipitation, may be the consequence of cold plasma flowing up field lines from the sunlit ionosphere. An increase in the density of thermal electrons could lower the wave phase velocity and lead to enhanced wave particle interaction. The concomitant particle losses would represent further precipitation of the substorm electrons injected near midnight.

A study of waves in the vicinity of the magnetopause has been carried out in conjunction with M. Neugebauer (JPL) and C. T. Russell (UCLA). Ogo-5 search coil magnetometer data at the magnetopause were examined for evidence of signals in the frequency range from 1-1000 Hz. Over three-fourths of the magnetopause crossings were devoid of detectable waves, indicating that the magnetopause is frequently a quiet region compared to the adjacent regions of the magnetosheath and magnetosphere. In the remaining crossings, the detected signals were similar in appearance to waves commonly observed in the magnetosheath (lion roars and broadband hiss). It is not known whether such signals are generated by instabilities occurring at the magnetopause or are carried there by plasma flow from the magnetosheath.

Occasionally, waves were observed in the magnetopause that were unlike either magnetospheric or magnetosheath signals. The most common signal of this type is a noise burst of short duration. Examples of magnetopause crossings which did, and did not, exhibit extremely low frequency waves were carefully studied. The data suggest that the magnetopause signals are correlated with the occurrence of steep gradients in the magnitude of the ambient magnetic field.

Interplanetary magnetic field and solar wind plasma observations made aboard Mariner, in route to Venus, and by earth satellites, Explorers 33, 34, and 35, have been used to investigate the propagation of magnetic sector boundaries between two widely separated locations. When pairs of corresponding sector bundaries were identified, the plasma velocities at earth were found to be systematically higher than at Mariner 5. Possible explanations that were investigated and rejected were instrumental defects or measurement errors and time variations at the solar source. One possible explanation is an average acceleration of the solar wind between the orbits of Venus and earth caused by interacting high velocity streams. The observed velocity differences also appear explainable as a dependence of the solar wind velocity on heliographic latitude with the higher latitude solar wind having a higher speed. The interval during which the data were acquired is part of a longer interval previously studied by Hundhausen, Bame and Montgomery who found evidence of a possible latitude dependence using Vela plasma data. The two complimentary studies appear to be in essential agreement and to imply an average velocity increase of 10 to 20 km/sec per degree of latitude.

The measured Mariner and Explorer solar wind velocities have also been used in an extrapolation of the sector boundaries back to their source locations on a solar surface to determine their corresponding latitudes and longitudes. The heliographic longitude of the inferred high latitude source systematically lagged the longitude of the low latitude source. This result is consistent qualitatively with the effect of differential solar rotation.

PUBLICATIONS

External

1. "Plasmaspheric Hiss" by R. M. Thorne, E. J. Smith, R. K. Burton and R. E. Holzer, J. Geophys. Res. 78, 1581 (1973).
2. "Identification of Interplanetary Tangential and Rotational Discontinuities" by E. J. Smith, J. Geophys. Res. 78, 2054 (1973).
3. "Observed Properties of Interplanetary Rotational Discontinuities" by E. J. Smith, J. Geophys. Res. 78, 2088 (1973).
4. "Discussion of the paper "Use of Two Magnetometers for Magnetic Field Measurements on a Spacecraft" by L. Davis, Jr., E. J. Smith and D. E. Jones, J. Geophys. Res., accepted for publication.

Meeting and Symposia Papers

A. American Geophyscial Union, December 1972
   1. "Midnight Chorus" by B. T. Tsurutani, A. M. A. Frandsen, P. S. Slosberg and E. J. Smith.
   2. "Solar Source Location and Propagation of Sector Boundaries" by E. J. Rhodes, Jr., and E. J. Smith.
   3. "Observations of the Magnetic and Plasma Structure of the Magnetopause" by M. Neugebauer, C. T. Russell, M. G. Kivelson and E. J. Smith.

B. American Geophysical Union, April 1973
   1. "Observations of ELF Hiss in Regions of Varying Plasma Density Both Inside and Outside the Plasmasphere" by K. W. Chan, R. E. Holzer and E. J. Smith.

2. "Midnight Chorus" by B. T. Tsurutani, A. M. A. Frandsen, M. Karspeck and E. J. Smith

3. "Dependence of the Solar Wind Velocity on Heliographic Latitude" by E. J. Rhodes, Jr., and E. J. Smith.

SOLAR WIND DATA ANALYSIS

NASA Work Unit 385-36-01-03-55
JPL 610-30030-0-8280
M. Neugebauer

OBJECTIVES

The objectives of this work unit are as follows: (1) To continue the reduction, analysis, and interpretation of the data acquired by the OGO-5 plasma spectrometer; (2) To correlate these data with simultaneous charged particle and field measurements on OGO-5 and other spacecraft (e.g., Pioneer 9, Apollo 12 ALSEP, Vela 5, etc.); (3) To prepare and deliver magnetic tapes, graphical displays, and appropriate documentation to the National Space Science Data Center; and (4) To report the results of the data analysis to the scientific community by publication and oral presentations.

PROGRESS

All positive-ion solar-wind data for 1968 have been submitted to the NSSDC together with appropriate documentation (Descriptions of the instrument, its modes of operation, the data formats, and estimated uncertainties in the calculated parameters). Each solar-wind spectrum is available on magnetic tape, graphical display, and microfilmed listing. Hourly averages of many of the solar-wind parameters are also available. Similar data for 1969-1971 will be deposited with the NSSDC during FY'74.

Magnetic field, plasma flux, and ELF wave data have been studied for several encounters of OGO-5 with the earth's magnetopause. In one case of a crossing in the near-earth region of the geomagnetic tail,

the structure agreed closely with a simple Chapman-Ferraro type of model with nearly complete neutralization of the charge-separation electric field. Small amplitude oscillations with apparent periods in the range 1 to 3 sec were observed at this, and other, crossings, in agreement with Eviatar and Wolf's predictions of the two-stream cyclotron instability being important for the tail magnetopause. The magnetic pressure was inversely proportional to the ion flux throughout most of the structure, which implies that the pressure balance was maintained principally by a variation of proton number density across much of the field-strength gradient. The inverse relation between B^2 and ion flux was observed at some, but not all, of the other crossings studied.

Many departures from this simple structure were observed at other magnetopause crossings; these included: (1) Field-strength bumps just inside the ion-flux gradients on non-tail field lines at which the field underwent a large rotation at the magnetopause; these interior maxima may be a diamagnetic effect due to the loss of trapped particles within one gyrodiameter of the magnetopause. The interior bumps were accompanied by exterior dips or local minima in field strength. (2) A well-defined double structure with a large discontinuity (possibly rotational) inside the ion-flux and field-strength gradients. (3) Different thicknesses of the magnetopause as measured by the changes in the field strength, the field direction, and the ion flux. (4) Occasional bursts of ELF waves. While some of these emissions resembled the "Lion Roars" often observed in the magnetosheath, other magnetopause emissions had spectra unlike the spectra of bursts observed in either the magnetosphere or the magnetosheath.

Power-spectral analyses of the solar-wind ion flux have been extended to cross-correlations with the fluctuations of the magnetic field using data from UCLA's fluxgate magnetometer on OGO-5. An interplanetary shock system observed by OGO-5 and Pioneer 9 has been studied in detail, especially with respect to the properties of the front of the helium-rich piston observed after the passage of a fast forward shock and ahead of a pair of reverse fast shocks. These studies of the solar-wind power spectra and of the interplanetary shock system were supported jointly by another task ("Theoretical Space Physics", NASA Work Unit 188-36-55-01) and are described more fully under that task.

PUBLICATIONS

External Publications

1. R. W. Fredricks, F. L. Scarf, C. T. Russell, and M. Neugebauer, "Detection of Solar-wind Electron Plasma Frequency Fluctuations in an Oblique Nonlinear Magnetohydrodynamic Wave", J. Geophys. Res., 77, 3598 (1972).

2. M. Neugebauer, C. W. Snyder, D. R. Clay, and B. E. Goldstein, "Solar Wind Observations on the Lunar Surface with Apollo 12 ALSEP", Planet. Space Sci., 20, 1577 (1972).

3. F. L. Scarf, R. W. Fredricks, C. T. Russell, M. Kivelson, M. Neugebauer, and C. R. Chappell, "Obervation of Current-Driven Plasma Instability at the Outer Zone--Plasma Sheet Boundary", J. Geophys. Res., 78, 2150 (1973).

4. T. W. J. Unti, M. Neugebauer, and B. E. Goldstein, "Direct Measurements of Solar-Wind Fluctuations Between 0.0048 and 13.3 Hz", Astrophys. Jnl., 180, 591 (1973).

5. L. F. Burlaga, J. Rahe, B. Donn, and M. Neugebauer, "Solar Wind Interaction with Comet Bennett (1969i)", Solar Phys., Accepted for Publication.

6. M. G. Kivelson, C. T. Russell, M. Neugebauer, F. L. Scarf, and R. W. Fredricks, "The Dependence of the Polar Cusp on the North-South Component of the Interplanetary Magnetic Field", J. Geophys. Res., Accepted for Publication.

7. T. Unti, M. Neugebauer, and C.-S. Wu, "The Shock System of February 2, 1969", J. Geophys. Res., Accepted for Publication.

Meeting and Symposia Papers

1. M. Neugebauer and T. Unti, "Major Discontinuities Between Shock Pairs", presented at a conference on "Flare-Produced Shock Waves in the Corona and Interplanetary Space", Boulder, Colorado, September, 1972.
2. M. Neugebauer, C. T. Russell, M. G. Kivelson, and E. J. Smith, "Observations of the Magnetic and Plasma Structure of the Magnetopause", presented at the American Geophysical Union Meeting, San Francisco, December, 1972.
3. T. W. J. Unti and M. Neugebauer, "The Helium Piston of 2 Feb 69", presented at the American Geophysical Union Meeting, San Francisco, December, 1972.
4. T. Unti, C. T. Russell, C.-S. Wu, and M. Neugebauer, "A Study of Features Between 0.1 and 1.0 Hz in Solar Wind Ion Flux Power", presented at the American Geophysical Union Meeting, Washington, April, 1973.
5. M. Neugebauer, "Solar Wind", presented at the Solar Neighborhood Meeting, Caltech, May, 1973.
6. C. T. Russell, M. Neugebauer, and M. G. Kivelson, "OGO-5 Observations of the Magnetopause", presented at the 7th ESLAB Symposium, May, 1973.
7. C. T. Russell, R. W. Fredicks, M. G. Kivelson, M. Neugebauer, and F. L. Scarf" OGO-5 Observations of the Physical Processes Occurring in the Disturbed Polar Cusp and the Cusp-Magnetosheath Interface", presented at COSPAR, May, 1973.
8. M. Neugebauer, "Progress in the Study of the Solar Wind", presented at the Convention of the Society of Women Engineers, June, 1973.

GENERAL RELATIVITY DATA ANALYSIS

NASA RTOP 385-41-01
JPL 610-60110-0-3910
J. D. Anderson

OBJECTIVE

To determine two relativity papers (β, γ) and the quadrupole moment J_2 in the Sun's gravitational field by means of least squares fits to radar, optical, and spacecraft data.

PROGRESS

Radar data taken at the Haystack and Arecibo radio observatories were mailed to JPL in November, 1971 by I. I. Shapiro of MIT. Over the past year, these data have been added to the JPL data set, which includes data from Stations 13 and 14 at Goldstone. As a result, 5040 radar observations of Mercury, Venus, and Mars, over a period of time from 1965 to 1973, have been processed in a form suitable for determining the relativity parameters and the quadrupole moment.

In addition 37,859 meridian circle observation (19,277 in right ascension, 18,582 in declination) of the Sun and all the major planets except Pluto have been processed for the relativity data analysis. These data, which extend from 1911 to 1972, have all been referenced to the FK 4 star catalog.

Range and Doppler data from Mariners 5, 6, and 7 have been processed in such a way that they can be incorporated in least squares solutions which include the radar and optical data. Data from Mariner 9 have also been processed under another work unit and as a result they are available for the relativity data analysis task.

In order to represent the radar data to sufficient accuracy for the relativity analysis, it has been necessary to compute a theoretical time delay for the radar data to account for propagation effects in the solar corona. Also, it has been necessary to account for the triaxiality of Mars as determined by the Mariner 9 occultation data.

Preliminary solutions which combine radar, optical, and spacecraft data have been obtained. These solutions indicate that the radar and optical data determine the precession of the perihelion of Mercury with a formal error of 0.2% when the quadrupole moment is assumed equal to zero and a formal 4% when the quadrupole moment is included in the solution. The relativistic time delay, produced by the solar gravitational field, is determined with a formal error of 2% from radar and optical data, largely because of the Haystack radar data during the January 1970 superior conjunction of Venus and the Goldstone data during the August 1971 superior conjunction. The addition of spacecraft data reduces this formal uncertainty of the time delay to 0.5%, but has very little effect on the determination of the precession of the perihelion.

Results for the determination of the relativity parameters and the quadrupole moment are very preliminary and can not be reported or published at this stage of the analysis. In particular, realistic errors, which will almost certainly be larger than the formal errors, must be determined in the near future. Also, it is very important to model the planetary topographies so that systematic errors which result from improper modeling will not affect the radar data. These two tasks will be completed within the next year and definitive results will be obtained for the parameters of concern.

Both the average center and the center of mass are used to calculate these statistical properties. From the standard deviations and correlations there is information on the speed of disruption of the fragments at the time of formation of the family. It is not possible to say exactly what this speed was for an individual case because the location in the orbit at the time of breakup remains unknown but it is possible to place lower limits on the velocities and to say something about their typical values. Thus, the fragments in a typical family dispersed with an rms speed of about 200 m/s and reliable families exist which require minimum speeds of 250 m/s. There are frequently significant correlations between the a, e, and sin i distributions so that a family is distinctly elongated in some direction. An ellipsoid is fit to the distribution and the direction and length of the three axes is calculated.

If it is assumed that all members of one family have the same albedo and spectral reflectivity then the brightness of the individual members as measured by the absolute magnitude may be used to get the magnitude of the original body before breakup. This same assumption is used in calculating the center of mass of the family. If albedos and spectral reflectivities were available these could be converted to diameters.

The examination of some of the larger families is intriguing. Both the Eos and Koronis families show a pattern of a dense core containing most of the members and a much less dense extension lying to one side of the core. In both cases the largest members lie in the cores. The Themis family is more involved. There is a well defined core surrounded by a complex of extensions. These extensions are mostly, but not exclusively, made

up of small objects. These extensions could be secondary families formed when a fragment of the original family was destroyed by another collision. They may also be some result of the original break-up itself analogous to the production of rays in impact craters.

The breakups which cause families range from giant cratering events, which leave the primary asteroid damaged but not destroyed, to collisions which caused complete disruption. For example, Ceres and Pallas both have small families associated with them but the fragments are very much smaller than the parent bodies. By contrast the Koronis family appears to be the result of the total destruction of an asteroid which was about 9 times the mass of the largest remaining fragment. When the parent body is only partly destroyed the large remaining fragment frequently lies at the edge of the family which means that the small fragments were only torn off of one side of the original asteroid. Such is the case with the Themis family. Sometimes the large remaining fragment appears to be broken into several pieces but still to be distinct from the smaller fragments. Thus the Maria family has five large objects which all lie on one boundary of the family. The largest three of these five are very tightly clustered and had very little speed of separation. The Alexandra family is even more curious. There are three equally large objects and many small fragments. Two of the three large objects are at opposite extremes of the family and the third lies in the center. The three lie in a straight line which matches the axis of elongation of the family.

In summary we are learning about how asteroid families were formed, what their properties are, and how the belt has evolved.

Toro

Under the heading of special objects the asteroid Toro, which can make close approaches to the earth, had its orbital evolution investigated over 5000 years. This object is peculiar in that its orbital period is almost exactly 8/5 that of the earth and 13/5 that of Venus. During a 5000 year integration the orbital period was locked on to exactly 8/5 of the earth's period for 3400 years and then it uncoupled from the earth and locked on to 13/5 of Venus' period. The switch over came as the orbit was getting farther from the earth and closer to Venus. These commensurabilities may temporarily stabilize Toro against collisions with the earth or Venus, though this is still not proven, but this is only a temporary advantage since Mars can remove Toro from the commensurabilities in about 3 million years. These results, done in cooperation with G. W. Weatherill of UCLA, have been accepted for publication in the Astronomical Journal.

Meteorites from the Asteroid Belt?

Investigation of the orbital evolution of the Lost City and Pribram meteorites showed that both were near resonances. These resonances with the so-called secular perturbations cause large oscillations in the orbital parameters with a million year time scale. For Pribam the oscillations in the perihelion distance due to the resonance was so large that it suggested that these resonances might be used to transport debris from the asteroid belt to the earth where it would fall as meteorites.

The mechanism that has been investigated is as follows. There is a parent body in the asteroid belt with elements which place it adjacent

to one of these long period resonances. There is a cratering event which ejects debris from the asteroid. If this ejecta is headed in the right direction with sufficient speed it will get into the resonance. The long period resonance causes the perihelion distance to decrease until it becomes earth crossing. After a few tens of millions of years some of the material will be swept up by the earth as meteorites. So far this mechanism seems adequate to get stoney meteorites from the belt rapidly enough and in sufficient quantity to match the data on stoney meteorites.

There are several dozen candidate objects near the resonances. Three were examined to determine what minimum speed is required for the ejecta in order to get deep enough into the resonance that its orbit can be made to go earth crossing. For 115 Thyra a minimum of 350 m/s is required while for 6 Hebe and 89 Julia speeds of 280 m/s are needed. Compared with the 200 m/s rms velocities seen in families the latter two asteroids are reasonable sources for meteroites while Thyra might give some material too.

Long integrations show that debris in these resonances with secular perturbations can be brought into earth crossing orbits in a little under one million years. Once in earth crossing orbits the debris will be swept up or ejected from the solar system in a few tens of millions of years. The importance of this result is that this time scale matches the cosmic ray exposure ages for stoney meteorites. Previous suggestions invoking Mars to drive asteroids or asteroidal debris in to earth crossing orbits required 100 million years or more and could not explain the cosmic ray ages of the stones without excessive erosion rates.

The second data point which any theory of meteorite origin must match

is the annual amount of material swept up by the earth. The calculations for these yields are still pretty rough but for 6 Hebe using the above limiting velocity of 280 m/s with an rms speed of 200 m/s for the ejecta and an infrared diameter of 200 kms for the asteroid gives about 15% of Hawkins value of 10^9 gms/yr. This yield is highly model dependent and can be made to go up or down by factors of several for reasonable models. With several dozen (mostly smaller) candidate asteroids meeting the annual impact rate for meteorites does not seem an impossible task.

Thus this mechanism for meteorite transport from the asteroid belt to the earth seems to match the measured ages and amounts of the stoney meteorites. Studies of the physical properties of the best of the candidate asteroids may allow the identification of the specific origin of various classes of meteorites.

Fireballs

The fireball study was intended to provide clues about the origin of meteorites. As the unexpected lead on meteorite origins was found the fireball project was deferred until FY'74 to allow that unscheduled project to be carried out.

PUBLICATIONS

1. Minor Planets and Related Objects XIV. Long Term Orbital Evolution of (1685) Toro, with G. W. Wetherill, Astronomical Journal, in press.

2. Meteorites from the Asteroid Belt? (abstract), Eos 4, page 233.

3. Secular Resonances (abstract), Bulletin of the American Astronomical Society, in press.

MEETING ATTENDANCE

1. Tucson, Arizona meeting on Toro, December 21, 1972, gave paper on Toro results.

2. American Astronomical Society Division on Dynamical Astronomy meeting in Cincinnati, Ohio, June 21-23, 1973, gave paper on using secular resonances to bring meteorites from the asteroid belt.

AAFE MICROWAVE TEMPERATURE SOUNDER

NASA Code 630-52-00-01-55

JPL 630-50008-0-8230

R. S. Iwasaki

OBJECTIVE

The objective of the AAFE Microwave Temperature Sounder is to develop an engineering model of a multi-channel microwave radiometer which will have the capability of measuring the temperature profile of the mesosphere and upper stratosphere. The radiometer is to have twelve microwave channels between 52 to 56 GHz, with nine of the channels requiring very high frequency stability. Miniaturization techniques are to be used to reduce the size and weight of the instrument for possible future spacecraft applications.

PROGRESS

The first six months of this three year program were concerned with the organization and implementation plans. The Development Test Plan and the Functional Requirements document have been prepared and are being modified. Much of the technology required for this radiometer is being developed in the Nimbus F SCAMS instrument. Thus, the areas of development for the microwave temperature sounder are the wide-band mixer preamps, the frequency stable local oscillators, the miniaturization of the IF and video electronics, and the development of active filters.

Stable Frequency Source

Temperature compensated crystal oscillators will be employed to maintain the high frequency stability requirement for the 53.331 GHz local oscillator and the 264.5 MHz secondary local oscillator. The 264.5 MHz oscillator crystal has been ordered and will be tested over the operating temperature range of 0 to 50°C to verify the frequency stability requirement of one part in a million.

The development of the 53.331 GHz local oscillator is more difficult because of the ten milliwatt power requirement for the mixer preamp. A promising engineering approach consists of using a frequency tripler after a phase-

locked Gunn oscillator source at 18 GHz since these sources are commercially available. The technique of phase-locking a Gunn oscillator at 53.331 GHz, although desirable because of smaller size and higher power outputs, has only recently been attempted.

Mixer-Preamp

The main procurement in the mixer-preamp area is the 53.331 GHz mixer preamp with an IF bandpass response of 10 to 300 MHz. The three other mixers to be used in the engineering model are already available.

Electronics

Electronic components for the breadboard tests have been ordered. A breadboard miniaturized IF amplifier has been fabricated but has not yet been evaluated.

Active Filters

A preliminary breadboard active filter was tested. Further tests are needed to determine the criteria for selecting either active or passive filters for each channel.

PLANNED ACTIVITIES

The primary emphasis for the next year will be the implementation of the hardware development program. Each of the breadboard subsystems will be individually tested to verify their performance over the operating temperature range before integration into the system. The breadboard radiometer, including the bench check-out equipment, is scheduled to be completed by the end of the fiscal year.

PUBLICATIONS

None

LUNAR SAMPLE - EXTINCT NUCLIDES

NASA Work Unit 914-40-56-78-55
JPL 606-05678-0-8280
E. Haines

OBJECTIVE

The objective of this task is to determine whether the short-lived fissioning nuclide, plutonium 244, existed in lunar materials early in lunar history.

PROGRESS

The work has proceeded in three stages: A preliminary study of terrestrial zircon; A search for candidate rock fragments from lunar soils, and; A detailed study of the particle track records of selected rock fragments. Although this work unit was officially ended on February 1, 1973, I have continued to work with the remainder of the allocated funds in order to bring the task to a satisfactory conclusion.

The study of terrestrial zircon demonstrated the difficulty of getting reliable track records from this mineral. Impurities appear as inclusions, and trace elements, notably uranium, occupy enriched zones. Those zones most enriched in uranium were metamict, and were rapidly destroyed during etching. Apparent ages calculated from fossil fission tracks were generally lower than ages established by other means. We concluded that in only the most favorable circumstances would zircon provide information about extinct fissioning nuclides.

Samples of lunar soils were searched for candidate rock fragments. KREEP basalts and anorthositic breccias were chosen. Large gains (>0.5 mm) were selected in order to avoid the influence of solar flare particles. Polished interior surfaces were searched by electron microprobe for phosphates and zircon. We learned that zircon is rare and the crystals are very small (<10 μ) in these materials, and turned our attention to the phosphates.

The uranium concentrations of individual grains were measured by fission track activation. Phosphate grains were etched incrementally, and plastic replicas of the surfaces were prepared after each step. Preliminary results show that a considerable track excess exists. More work is required to show whether any of the excess fossil tracks can be related to an extinct nuclide.

I expect that this work can be concluded with the small remaining funds.

PUBLICATIONS

None.

LUNAR SAMPLE ANALYSIS
SPECTRAL REFLECTANCE AND VITRIFICATION EFFECTS
NASA WORK UNIT 914-40-58-19-55
JPL 606-05819-0-8260

D. B. Nash
J. E. Conel

OBJECTIVE

This is a continuing study of the spectral reflectance properties of lunar rock and soil. The objective is to gain further understanding of how the mineral and glass components in a rock mixture control the bulk reflectance properties of the mixture in the spectral range 0.3 to 2.5 μm. These studies are directed toward refining a telescopic method for measuring mineral composition and abundance on lunar and planetary surfaces.

PROGRESS

The near-IR and visible spectral reflectance and albedo of Soviet Luna 20 highland material were measured and found to be similar to those properties of Apollo 16 highland material. The anorthositic character of these samples is distinctly evident in their spectral reflectance curves and is different from mare samples. These results indicate that the highlands are rich in plagioclase and relatively poor in pyroxene, ilmenite, and glass compared to mare surface material.

Luminescence studies on Apollo 14 sample 14053 indicate that a small (~ 6%) synergistic effect may exist between near-uv solar radiation and solar wind protons that could slightly enhance luminescence generation on the the moon's surface. The magnitude of this effect, however, is too small to account for the orders-of-magnitude discrepancy between reported telescopic measurements of lunar luminescence and the limitation of lunar luminescene intensity based on lab studies of moon rocks.

The spectral reflectance systematics have been experimentally determined for mixtures of plagioclase, pyroxene, and ilmenite which are the predominant mineral phases making up virtually all lunar rock materials examined to date. These results indicate that the spectral elements of a composite reflection spectrum of an unknown reflecting surface can be related in a systematic way to the composition and abundance of crystalline mineral phases in the material producing the spectrum. Further, these results indicate that standard calibration curves can be produced using mineral separates from returned lunar samples so that the more accurate interpretations can be made of lunar surface spectra obtained by telescopic methods.

PUBLICATIONS

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ELECTRON SPIN RESONANCE STUDIES OF LUNAR SAMPLES

NASA Work Unit 914-40-58-42-55
JPL 606-05842-0-8260

F. D. Tsay

OBJECTIVE

The objective of this task is to investigate with electron spin resonance (ESR) technique the nature and origin of the metallic Fe phases in the returned lunar samples.

PROGRESS

Apollo 16 fines from three sites were investigated together with a high-grade metamorphic rock. The ESR signals observed for the Apollo 16 fines are found to be essentially similar in g-value, in lineshape asymmetry and in temperature dependence to those previously observed for the Apollo 11-15 fines. On the basis of these similarities, it is concluded that these ESR signals like those detected in the Apollo 11-15 fines are principally ferromagnetic in nature arising from metallic Fe phases having the body-centered cubic structure, and not from hematite, magnetite, or any other ferric oxides.

The ESR linewidth observed for the Apollo 11-16 fines has been shown to correlate with the average Ni and/or Co content in the metallic Fe phases of the sample. For the three Apollo 16 fines investigated the ESR linewidths are found to be essentially identical. This together with a high Ni content in the metallic Fe phases of these samples as determined from ESR linewidth correlation indicates a common source of meteoritic origin for the metallic Fe phases of these samples. Significant variations are observed in the

total metallic Fe content as well as in the total Ni content for the three Apollo 16 fines investigated, in particular, between the fines from South Ray crater and from North Ray crater. These variations appear to correlate with the surface exposure ages of the samples.

The ESR signals observed for the rock samples are found to be dominated by a broad component which can be attributed to ferromagnetic centers of metallic Fe whose grain size and shape are apparently different from those observed for the fines. The intensity, lineshape and linewidth of the ESR signals detected in the rock samples are found to correlate with the metamorphic grades of the samples.

PUBLICATIONS

External Publications

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RETUR D LUNAR SAMPLES PORPHYRIN ANALYSIS

NASA Work Unit 914-40-59-15-55
JPL 606-05915-0-8260

J. H. Rho, A. J. Bauman and E. A. Cohen

OBJECTIVES

The objective of this experiment is to detect porphyrins and other fluorescent aromatic compounds which may be present in amounts greater than 10^{-13} moles per gram in the lunar crust samples.

The detection of such compounds in the lunar sample not only would bear great significance with respect to chemical evolution and origin of life on the earth and other planets, but also would provide an important clue to the nature of the primordial solar system.

PROGRESS

1. Analysis of Apollo 15 Deep Drill Core Samples and Apollo 16 Surface Fines for Porphyrins

Apollo 15 cores 15002 (160-200 cm down) and 15001 (200-240 cm down), each 3 gm in size, were Soxhlet-extracted with benzene-methanol 3:2 v/v and the extracts examined fluorometrically for porphyrins. An Apollo 16 surface fines sample 65500,10 collected from Station 5 (5 gm) was similarly extracted. The extracts contained no porphyrins.

Fluorescence spectra of the lunar sample extracts were obtained on an Aminco-Bowman spectrophotofluorometer at excitation wavelengths from 350 to 450 nm. No fluorescence attributable to porphyrins or different from the blank was found, even with computer-enhancement of the Data (Rho, et al., 1972). The averages of 16 scans of fluorescence from 550 to 750 nm were recorded on a signal analyzer at 5 sec per scan rate. 180 data points in this range were

processed by the least squares method. When the deviations from the blank were subtracted from those of the lunar sample extracts, no features attributable to porphyrins remained.

With this method one could conservatively detect 0.1 ng of Ni-mesoporphyrin IX (2×10^{-13} moles), a typical metalloporphyrin. The lunar samples examined in this study, Apollo 15 (15001, 15002) and Apollo 16 (66500) weighed 3,3 and 5 gm, respectively so that if we assume the presence of Ni-mesoporphyrin IX or equivalent this means that we could have detected 7×10^{-14} moles/gm for the core samples and 4×10^{-14} moles/gm for the surface sample.

This work therefore strongly suggests that porphyrins or aromatic hydrocarbons are not present in these lunar samples in significant amounts.

2. Apollo 15 Lunar Sample Contaminated with LM Exhaust Products

Because "porphyrin-like" compounds have been attributed to synthesis from the dimethyl hydrazine exhaust (Simoneit, et al., 1969; Hodgson, et al., 1972) we examined an LM exhaust-contaminated sample (15013,1) from the area just north of the LM in order to determine the fluorescent properties of the compounds present. The sample was collected in a Special Environment Sample Container (SESC) and later opened in a dry helium atmosphere (Simoneit, et al., 1972). One portion of the sample was extracted in air and another in argon for comparison because Hodgson (Hodgson, et al., 1972) has suggested that porphyrin precursors in an Apollo 12 sample may have oxidized to porphyrins during the course of extraction in air. It thus seemed possible that the discrepancy between their work and ours was due to such oxidation, as all our previous extractions were carried out in argon.

The "air extract" of 15013,1 did not fluoresce appreciably above background but the "argon extract" contained a compound which absorbed at 425 nm and fluoresced at 660 and 725 nm with a maximal excitation at 425 nm. The unknown was present at about one part per billion and had a fluorescence spectrum which was porphyrin-like but with a maximum shifted 50 nm further toward the red than that of typical porphyrins. Partition between 6 N HCl and benzene left it in the benzene phase, unlike the porphyrin-like compounds isolated from similar samples previously (Hodgson, et al., 1971). The fact that "porphyrin-like" compounds were found in the "argon extract" but not in the "air extract" gives no support to the hypothesis of Hodgson (Hodgson, et al., 1972) that porphyrins may form in Apollo samples extracted in air by oxidation of porphyrin precursors present. The partition and chemical properties of the fluorescent species reported here also differ from those previously noted (Hodgson, et al., 1970, 1971) for reasons not clear at this time.

The samples studied (15013,1) were exhaust-contaminated so it is not clear whether the fluorescent unknown is indigenous or not. If it is indigenous an understanding of its nature would be important to chemical evolution theory. Future lunar studies should allow for the possibility that fluorescent artifacts may be present in sampling areas near the landing site.

FUTURE

A 10-gram quantity of Apollo 17 surface fines has recently been received and will be examined by the end of August 1973. We will then be prepared to analyze any additional Apollo 17 samples as they become available.

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